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Journal of Experimental Psychology

Journal of
Experimental Psychology

VOL. I, No. 6. DECEMBER, 1916

REFLEX SECRETION OF THE HUMAN PAROTID GLAND

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Discovery of the importance of internal secretions for physiological psychology is leading to a widespread interest in the conditions governing secretion. The difficulties of studying the activity of the ductless glands in man are at present almost insurmountable and their relation to the nervous mechanism and to the changing habit-systems of the individual must be judged largely from the conditions in other animals or from analogy with such glands as can be studied directly in man. In an earlier paper I have summarized the work which has been done upon the reflex secretion of the human salivary glands and outlined the problems of psychology which a study of human salivary reactions may help to solve. The chief interest of these glandular reactions for psychology lies in the complex nature of some stimuli to secretion and in the formation of conditioned reflexes (habits of secretion). Before a study of these complex activities can be undertaken it is necessary that we have a fairly complete knowledge of the simpler stimuli influencing secretion. The existing studies of unconditioned secretion in man are too incomplete to give this and are, hence, inadequate as a foundation for work upon conditioned reflexes. The experiments reported in the following pages were undertaken in preparation for a study of the relation of secretion to the more complex activities of the individual and have been directed, primarily, toward the discovery of the stimuli

which may influence the secretion of the parotid gland directly or indirectly. While the data obtained is largely physiological, some of the reactions observed seem to rival the complexities of the language mechanism and place the topic of reflex secretion very near the border-line between the sciences of physiology and psychology.

For suggestions concerning the general plan of the work I am indebted to Professor J. B. Watson. In many of the tests, also, in which more than one observer was required and in those in which I have acted as subject he has given generously of his time in conducting the experiments.

Technique

The only method of obtaining the secretion of the parotid gland in normal human subjects that has been used by physiologists is that of draining off the saliva from a small canula inserted into the mouth of Stenson's duct. As Ordenstein ('60) states, this method is not very suitable for quantitative work for the reason that one never can be sure that some of the secretion is not leaking past the canula. The expanding walls of the duct also frequently let the canula slip out. A few tests with small canulas quickly convinced me that the method is not practicable for long-continued work.

Fig. 1. Drainage tube used for collecting the secretion from Stenson's duct.

Finally the instrument shown in Fig. 1 was devised and has proved quite satisfactory for the study of the secretion of the parotid gland. It consists of a metal disc 18 mm. in diameter in which two concentric chambers, *a* and *b*, are cut. The inner of these is 10 mm. in diameter and 3 mm. deep; the outer, in the form of a circular groove, is 2 mm. wide and 3 mm. in depth. The two chambers open through the back of the disc into two separate tubes, *c* and *d*, of about 2 mm. bore and 15 cm. length. The tubes are of silver, soft-drawn for greater flexibility, and the disc is heavily

silver-plated. In use, the instrument is placed against the inner surface of the cheek so that the central chamber covers the mouth of Stenson's duct and the air is exhausted from the outer chamber by a suction pump, when the disc clings tightly to the cheek. The saliva is free to flow into the central chamber and thence through the tube, *c*, to a suitable measuring device, without constriction of the duct or unusual resistance. When the mouth is closed the tubes lie between the cheek and the upper molars and pass out through the corner of the mouth. The instrument interferes little with talking or eating and may be worn for several hours without discomfort.

For the submaxillary glands a slight modification of the instrument has proved fairly useful. In this the tubes are directed at right angles to the surface of the disc and are bent sharply to pass over the lower incisors. The close proximity of the mouths of Wharton's ducts to the mandible makes it necessary to have the central chamber eccentric so that the suction chamber is reduced to a width of 0.5 mm. on the side next to the mandible. The ducts of the two submaxillary glands open so close together that both must be covered by the instrument and their secretions can not be obtained separately. The great sensitivity of the mucosa of this region and the necessity for depressing the tongue in swallowing make this instrument less satisfactory than that for the parotid.

Various methods of recording the quantity of secretion have been tried, but for the present work the mere counting of the drops as they fall from the drainage tube has seemed sufficiently accurate. The drops vary in size with changes in the rate of secretion and the viscosity of the saliva. With the drainage tube used in the greater part of the work the size of the drops varies from a minimum of 0.06 c.c. to a maximum of 0.07 c.c. with extreme changes in the viscosity of the secretion. For more detailed study of the quantitative relations of the secretion than has been undertaken here measurements of both the quantity and chemical composition of the saliva will be necessary.

The Normal Rate of Secretion of the Parotid

Before the rate of secretion of the parotid in the absence of extero-stimulation can be determined the stimulating effect of the method of collecting the saliva must be tested. Where a fistula exists, such stimulation is improbable but where a canula or suction cup is placed in the mouth some excitatory effect is to be expected. The effect of mechanical stimulation from the drainage tube can be tested only indirectly; and excitation from the suction cup described earlier seems ruled out by the following facts. (1) The presence of a large glass rod or other tasteless object in the cheek with the drainage tube does not increase the rate of secretion. (2) Mechanical stimulation of the cheek and gums, where not covered by the drainage tube, does not call out reflex secretion until it becomes strong enough to excite reflex avoiding movements. (3) Manipulation of the drainage tube after adjustment, while it may force out a few drops of secretion from the receiving chamber, does not increase the rate of secretion as measured in successive minutes. From this evidence it seems safe to conclude that the secretion collected from the drainage tube represents fairly the normal secretion of the gland.

To determine the variation in secretion under conditions of as little stimulation as possible I have tested a number of subjects in a quiet state, computing the rate of secretion from a half hour's observation during which the flow remained fairly constant. Measurements were made at different hours in order to control, to some extent, the enteric stimuli. In each case the subject remained quiet, with mouth closed, but without inhibition of the swallowing reflex or of movements adjusting the position of the body. The results of the tests are summarized in Table I. The children tested give a secretion considerably less than the average for adults. The great amount of individual variation makes it impossible to be certain of the sex differences noted by Tuczek ('76).

The data shown in the table can not be considered as showing the rate of secretion in the absence of stimulation. Marked extra-organic stimulation is lacking but the gland is

TABLE I

THE RATE OF SECRETION OF THE LEFT PAROTID GLAND WITHOUT EXTERO-STIMULATION

Subject		Secretion, C.c. per Hour	Conditions of Test
Age	Sex		
26	♂	3.81	11.30 A.M. No food for 12 hours.
		7.74	1.00 P.M. After lunch.
35	♂	1.47	12.00 A.M. Before lunch.
		1.98	1.00 P.M. After lunch.
38	♂	3.47	1.30 P.M. Under alcohol.
		3.24	11.30 A.M. Before lunch.
		6.98	2.00 P.M. After lunch.
24	♂	1.90	9.00 A.M. No breakfast.
		1.30	5.00 P.M. Before dinner.
		3.00	7.00 P.M. After dinner.
25	♀	0.39	11.30 A.M. Before lunch.
		0.65	1.30 P.M. After lunch.
		1.19	10.00 A.M. Two weeks later.
27	♀	4.64	12.00 N. Before lunch.
		6.60	1.00 P.M. After lunch.
8	♂	0.60	3.30 P.M.
12	♀	0.43	4.00 P.M.

subject to almost constant stimulation from the receptors of the mouth and throat. Table II. shows the variations in the rate of secretion in a subject remaining quiet for 20

TABLE II

VARIATIONS IN THE RATE OF SECRETION DUE TO SWALLOWING

The figures represent the time in seconds intervening between the formation of successive drops. The rapid rate at first is the result of an acid stimulus given to make sure that the instrument was properly adjusted.

Drop	Time	Drop	Time	Drop	Time	Drop	Time
1	—	13	60	25	80	35	55
2	4	14	73	26	120	36	145
3	4	15	152	27	185	37	155
4	9	16	135	28	215	38	155
5	13	17	173	29	209	39	110
6	10	18	204	Shifted position		40	67
7	10	19	125			Swallowed	
8	15	Swallowed		30	88	41	15
Sucked	cheeks	20	7	Swallowed		42	15
9	10	21	4	31	19	43	56
10	20	22	16	32	14	44	67
11	31	23	30	33	30	45	83
12	39	24	38	34	20	46	172

minutes and partially inhibiting the swallowing reflex. Swallowing is seen to result in an accelerated flow, persisting

for some minutes, and movements of the body also seem to have a slight stimulating effect.[1]

In some subjects, when particularly quiet, the activity of the parotid may cease completely for five or more minutes. Whether this is due to the absence of stimulation or to some inhibitory process is difficult to determine. The data upon

TABLE III

A COMPARISON OF THE ACTIVITY OF THE RIGHT AND LEFT PAROTID GLANDS

The ratio of size of the drops from the right and left sides is 49 to 50.

Stimulus	Total Secretion in Drops		Time Required for the Secretion Recorded (Minutes)
	Right	Left	
No stimulation	29	29	15
Chewing tasteless cube			
Between incisors	13	16	2
Between right molars	15	6	2
Between left molars	4	19	2
Between right and left molars	14	17	2
Sodium chloride, 10% solution			
Uniformly distributed	18	20	2
In right cheek	6	6	1
In left cheek	8	8	1
Hydrochloric acid, 2.50%			
On right side of tongue	19	12	1
On left side of tongue	12	30	1
In right cheek	15	7	1
In left cheek	4	12	1
Uniformly distributed	19	21	1
Tongue scraped with pointed rod			
Right side	6	3	1
Left side	6	10	1

paralytic secretion show that after destruction of its nerve supply the submaxillary gland continues to secrete for some months until it finally degenerates. Bradford ('88) failed to obtain this paralytic secretion from the parotid in dogs whence it seems that in the absence of stimulation the parotid does not secrete. No observations on man after section of the nerve supply of these glands are available.

The Relative Activity of the Two Parotid Glands.—Colin ('54) states that in ruminants the parotid glands function alternately, not only when food is being chewed on one side

[1] From the tests reported on page 484 it seems probable that the apparent excitatory effect of shifting the position really acts by removing the inhibitory effect of muscular tension.

of the mouth but even in the absence of food. In man, for the most part, the glands secrete equally and simultaneously. Drainage tubes were placed over both of Stenson's ducts and the subject was allowed to remain without extero-stimulation for fifteen minutes. The average number of drops per minute secreted by the two glands was: right parotid 1.92; left parotid 1.92 drops. The quantity of secretion from the two glands was thus almost exactly the same (the ratio in the size of the drops from the two drainage tubes being as 49 to 50) and the variations in rate were the same for both. Table III. shows the relative reactions of the two glands to various stimuli. The reactions of the left seem to be somewhat more vigorous than those of the right, which accords with the fact that the subject habitually chews on the left. Bilateral stimulation affects both glands equally. Stimulation of one side of the mouth stimulates the gland of that side to a greater extent than the other. Each gland seems to be most intimately associated with the receptors of its own side.

Reflex Secretion to Stimulation of the Mouth

The direct reflex of the parotid seems to be excited only by stimulation of the receptors within the digestive tract, chiefly those within the mouth. A number of diverse stimuli applied here will excite the reaction and the chief problems are concerned with the distribution of sensitive areas and the quantitative relations of the secretion.

Thermal Sensitivity.—Wulfson,[1] Popielski ('09), and Brunacci ('10) have raised the question of the excitability of the parotid by thermal stimuli. The work of the latter shows excitability only by temperatures above 55 and below 15 degrees Centigrade. These results are confirmed by the following results of my own.

The subject, *L*, whose normal rate of secretion from the left parotid during experiments is about 1 drop per minute, was required to take three sips of water (about 10 c.c.) in quick succession at each of the following temperatures. The number of drops secreted during the three minutes following stimulation was recorded as follows:

[1] Cited from Babkin ('14).

Temperature of Water	Drops of Saliva
66 degrees	13
61 "	10
55 "	6
52 "	7
41 "	5
36.5 "	7
25 "	7
18 "	7
13 "	10
10 "	8
0 "	10

Increased secretion above that resulting from mechanical stimulation of the mucosa appears only with temperatures above 55 and below 18 degrees. These are well beyond the limits determined by Head and Sherren ('05) for protopathic sensation and suggest the absence of any direct reflex connection between the thermal receptors of the mouth and the parotid glands.

Mechanical Sensitivity.—Mechanical stimulation of the oral mucosa is considered by most investigators to be an efficient excitant of parotid secretion. A careful test of this without interfering stimuli and with the possibility of conditioned reflexes reduced has failed to confirm this view. Table IV. shows the reflex secretion from the left parotid gland obtained from two subjects after mechanical stimulation of the mouth. Stimulation of restricted areas of the mucosa is seen to have little effect except at the back of the tongue and soft palate, where nausea is produced. Some summation of stimuli is apparent in stimulation of the tip of the tongue with a stiff brush, the individual bristles of which gave less violent stimulation than the sharp points of the dividers. In general it seems that very little reflex secretion is obtained from the parotid in response to mechanical stimuli.

The Effects of Chewing.—The experimental literature shows little agreement as to the excitatory effects of chewing movements upon the parotid and no one has attempted an analysis of the relative influence of the different end-organs stimulated when some solid object is chewed. A few tests of the

TABLE IV

REACTIONS TO MECHANICAL STIMULATION OF THE ORAL MUCOSA

The effect of the stimulus is shown by the increase in secretion between the minute before and the minute during stimulation.

Subject	Stimulus	Secretion	
		Before Stimulation	During Stimulation
H....	Blunt glass rod rubbed against		
	lower lip	0	0
	tip of tongue	0	0
	side and back of tongue	1	1
	ditto with tongue-movements	0	1
	soft palate	1	2
L.....	(Stimulus applied for 30 seconds)		
	Blunt ivory rod rubbed against		
	lips	3	2
	tip of tongue	2	5
	middle of tongue	2	5
	back of tongue	2	12
	gums at right	2	5
	hard palate	2	8
	soft palate (nausea)	2	13
	Stimulation with points of dividers		
	lips	2	2
	tip of tongue	2	3
	middle of tongue	2	5
	hard palate	2	5
	Stimulation with stiff brush		
	tip of tongue	3	7
	middle of tongue	2	9
	Stimulation with tasteless cube		
	lower surface of tongue	2	3
	rubbed violently between tongue and left molars	2	5
	between tongue and hard palate	2	4
	Stimulation with 1 c.c. of fine sand		
	rubbed between tongue and hard palate	3	8

effects of chewing convinced me that the adequate stimulus is more complex than any of the previous workers have suggested. A series of experiments was made to distinguish the elements in the constellation of stimuli involved in chewing that are effective in exciting secretion. The tests are summarized in Table V. From the data in this and the preceding table the following conclusions seem justified. (1) Contractions of the muscles of the mandible or changes in the tension of its ligaments do not excite secretion. (2) Pressure on the teeth is, alone, not an effective stimulus. (3) No amount of mechanical stimulation of the mucosa excites as much secretion as light contraction of the teeth

upon a foreign object. Chewing does not excite secretion solely by stimulation of the mucosa. (4) Combined mechanical stimulation of the tongue and pressure on the teeth are not so effective as less violent stimulation of the same sort when some object is held between the teeth. (5) Active secretion is excited by the presence of a foreign object held between the teeth.

TABLE V

EXPERIMENTS ON THE STIMULUS FROM CHEWING

The stimulus was continued in each case for one minute. The total number of drops secreted by the left parotid during and after stimulation until the rate returned to normal was found: for comparison the number of drops secreted during an equal time before stimulation is given. The tongue was depressed and unstimulated except where noted.

Stimulus	Secretion			
	Before Stimulation, Minutes		During Stimulation, Minutes	
	1	2	1	2
Chewing movements with contact on normal facets	3	3	3	3
Chewing without contact between teeth	4	5	4	5
Rhythmic contraction of masseters, mouth closed	4	3	3	3
Chewing movements with contact on unused facets	3	3	3	3
Tongue chewed violently between left molars	3	2	10	2
Tongue chewed violently between right molars	3	2	5	2
Foreign object in the mouth (For stimulation of mucosa see table IV.)				
Hard rubber cube held lightly between second molars on left	1	1	5	1
Same, gripped tightly	2	2	10	2
Same, chewed lightly	4	1	13	1
Same, chewed violently	2	2	38	2

The reaction seems to be to the total situation rather than to any simple stimulus. The following observation is especially difficult to explain as a reaction to a simple stimulus. With lips drawn back and tongue depressed the subject apposed the first pair of incisors on the left and continued strong rhythmic contractions of the masseters for two minutes, exerting considerable pressure on the teeth and breathing the while through the nose. In the two minutes preceding these movements 3 drops of saliva were secreted; in the two minutes during chewing 4 drops. A disc of hard rubber 2 mm. in thickness was then placed between the same two

incisors without contact with the lips or tongue and the chewing rhythm was renewed with the same strength as before. In the two minutes preceding chewing 4 drops of saliva were secreted; in the two minutes during chewing 13 drops. The stimuli added to the local situation by the hard rubber disc were first, tactile, from the particular type of mechanical stimulation transmitted through the teeth, and second, kinæsthetic, from the slightly greater separation of the jaws by the disc. The last is ruled out by further tests with discs of different thickness, to all of which the gland secreted equally. It is not possible to distinguish between the elements of the tactile stimulation at present. Irregular and varying pressure on the teeth is not alone an effective stimulus. The stimulus to secretion seems to be no less complex than that by which knowledge of a foreign object between the teeth is gained.

Colin ('54) and Zebrowski ('05) have found that chewing on one side of the mouth excites chiefly the gland of that side. My observations bring out the additional fact that when chewing occurs on both sides at the same time, less secretion is produced than when one side only is stimulated.

Two equal cubes of hard rubber were used with the drainage tube on the left Stenson's duct. One cube was placed between the left second molars, chewed for two minutes, and then removed. When the rate of secretion returned to normal both cubes were placed between the second molars on the right and left respectively and chewed for two minutes. This was repeated three times with the following results.

Stimulus	Drops of Secretion per Minute
Cube on left	12
Cubes on left and right	5
Cube on left	7
Cubes on left and right	3
Cube on left	8
Cubes on left and right	2
Average, cube on left	9.0
Average, cubes on left and right	3.3

The reduction of secretion with bilateral stimulation must be due either to an inhibitory effect of stimulation of the

molars of one side upon the gland of the opposite side, or to some peculiarly effective stimulus arising from asymmetrical movements. Unequal tension on the ligaments of the jaw seemed to fulfill the latter alternative but both passive and active twisting of the jaw are alone without effect so that alterations in the tension of the ligaments seem excluded.

The stimulus offered by chewing has been dwelt upon at some length because the reaction to it illustrates, perhaps better than any other, the complex integration involved in the salivary reflex. Chewing upon a tasteless object excites profuse secretion yet no single element in the complex of stimuli is capable of calling out any marked reaction. The reflex secretion to the stimulus of chewing can not be considered the sum of lesser reactions to the individual components of the stimulus; it is rather a reaction to a particular pattern of stimuli, occurring not at all when any element of the pattern is omitted. This pattern seems no less complex than that by which we recognize the presence of an object between the teeth. The reaction is, however, dissociated from the language mechanism in that it is automatically adjusted to the position of the foreign object in the mouth and is not conditioned by the ordinary inhibitory processes which affect the reactions of striped-muscle.

There is some evidence for an equal complexity in other unconditioned salivary reflexes, particularly in the relations of the stimuli to reflex swallowing and to secretion but the analysis of these is as yet incomplete.

Reactions to Gustatory Stimuli.—A number of extensive studies of reflex secretion to gustatory stimuli have been made. Those of Popielski ('09) and Zebrowski ('05) are the most complete available. Sensitivity to acids, salts, alkalis, fats, and to a large number of food substances has been demonstrated. Popielski has shown that the quantity of secretion elicited by an acid is rather accurately proportional to the degree of ionization of the acid but failed to obtain any uniformity in the reactions to other substances. From tests with sand and water he concluded that the amount of secretion is directly proportional to the quantity

of the stimulus-substance used. Zebrowski, from experiments in which his subjects chewed and swallowed measured quantities of bread, concluded that the amount of secretion is proportional to the square-root of the intensity of the stimulus. Brunacci ('10) points out the complexity of the stimulus involved here and thinks that the ratio applies only to the particular case.

The intensity of the reaction to gustatory stimuli is subject to modification by the number and relative excitability of the end-organs stimulated, by the quantity of saliva present in the mouth to dilute the stimulating substance, by the amount of mucus which may be precipitated over the taste buds, and by the length of time during which the stimulus persists, as well as by the quantity and quality of the taste substance placed in the mouth. None of these factors was adequately controlled in Zebrowski's experiments so the significance of his results is questionable. It is particularly difficult to control the distribution of the taste substances in the mouth and the length of time during which the stimulus remains active. In the following tests some attempt was made to do this but with no great success, and the results are at best only approximately correct.

The subject, with the drainage tube on the left Stenson's duct, was warned ten seconds before stimulation and cleared his mouth of saliva as well as possible by swallowing. A measured quantity of solution was then placed in his mouth from a pipette. The subject distributed this over the surface of his tongue by quick movements and held it in his mouth for one minute, then swallowed it, rinsing his mouth immediately with 5 c.c. of water. The volumes of secretion obtained with different quantities of solution are given in Table VI. With only one exception a lesser increase in the secretion follows an increase in the quantity of solution than is to be expected from Zebrowski's formula. The irregularity of the results obtained with chemical stimuli may be due to the fact that with increase in the quantity of solution more taste buds are stimulated. The larger quantities stimulate the base of the tongue and the soft palate which are more

TABLE VI

THE RELATION BETWEEN THE QUANTITY OF SECRETION AND THE QUANTITY OF THE STIMULATING SOLUTION

The second column gives the quantity of secretion during one minute of stimulation and two minutes after removal of the stimulus. The third column gives the quantity expected from Zebrowski's formula.

Stimulus	Secretion in Following Three Minutes (Drops)	Expected Secretion
NaCl 1.00%		
1 c.c.	10	—
2 c.c.	11	14
3 c.c.	12	20
HCl 1.00%		
1 c.c.	17	—
2 c.c.	20	24
3 c.c.	28	29
5 c.c.	28	38
10 c.c.	44	54
HCl 0.25%		
1 c.c.	12.8	—
2 c.c.	16	18
HCl 0.50%		
1 c.c.	17	—
2 c.c.	20.5	24
HCl 2.50%		
1 c.c.	28.7	—
2 c.c.	42.0	40
Cane sugar 10.00%		
1 c.c.	4	—
2 c.c.	4	5.7
3 c.c.	6	6.9
4 c.c.	6	8.0
5 c.c.	4	8.9
10 c.c.	6	12.5
15 c.c.	8	15.5
25 c.c.	7	20.0

sensitive to some than to other chemicals (Table VIII.). Thus the reaction to large quantities of acid is relatively greater than to equal quantities of sugar. The relative excitatory effects of different quantities of solution is doubtless due in large measure to this stimulation of a greater or lesser number of taste buds but other factors also seem to be of importance. The duration of maximal stimulation varies with the quantity of solution since the lesser quantities are diluted more rapidly by saliva than the greater. There

is, further, a difference in the mechanical stimulation which, perhaps conditioned by gustatory stimuli, may be effective in exciting secretion by some such complicated mechanism as that involved in the reaction to chewing.

The Relation of the Quantity of Secretion to the Intensity of the Stimulus.—The difficulties in the determination of the excitatory effects of different concentrations of chemical solutions are practically the same as those met with in the study of the effects of different quantities. The experiments on man have shown no more than that strong solutions are more effective salivating agents than weak ones. Accurate results have been made almost impossible by the difficulty in removing the stimulating agent from the tongue at a specified time, the presence of a constant secretion independent of oral stimulation, the persistence of secretion after strong stimulation of the gland, and the possibility of paralysis of the receptors by high concentrations of the solutions.

The last of these is illustrated by the following experiment. Small discs of cotton, 1 cm. in diameter, were saturated with acid solutions and placed, one after the other, over the same group of papillæ on one side of the tongue. The cotton was allowed to remain in place for one minute and the record of drops was taken for this minute only. The same solutions were applied with a brush to a small group of fungiform papillæ. The following quantities of secretion were obtained.

Stimulus	On Side of Tip	On Fungiform Papillæ
HCl 0.25%	4 drops	2 drops
" 0.50%	4 "	3 "
" 1.00%	6 "	2 "
" 2.50%	8 "	3 "
" 5.00%	11 "	6 "
" 7.50%	8 "	5 "
" 10.00%	6 "	4 "

The decrease in the quantities of secretion with solutions of more than 5.0 per cent. is the result of injury to the taste buds. Desquamation of the stimulated areas followed the experiment.

A series of tests was carried out with solutions of hydro-

chloric acid and of sodium chloride. Other taste substances, quinine sulphate in particular, could not be used because of the difficulty of removing them from the surface of the tongue without prolonged washing. In the tests with salt and acid the following technique was adopted. Thirty seconds before each test 5 c.c. of water were placed in the subject's mouth to dilute the mucus present and the mouth was cleared of saliva as well as possible by swallowing. The remaining procedure was the same as that described on page 473. Each test was delayed until the secretion returned

TABLE VII

THE RELATION OF THE QUANTITY OF SECRETION TO THE INTENSITY OF THE STIMULUS

Drainage tube on the left duct. Stimulus applied for one minute and the total secretion during this and the following two minutes recorded.

Subject	Stimulus	Drops of Secretion in 3 Minutes	Average of — Trials
L.....	HCl 0.25%, 1 c.c.	12.8	5
	" 0.50%, 1 c.c.	17.0	3
	" 1.00%, 1 c.c.	20.0	3
	" 2.50%, 1 c.c.	28.7	4
	" 5.00%, 1 c.c.	40.5	2
	" 0.25%, 2 c.c.	16.0	2
	" 0.50%, 2 c.c.	20.0	2
	" 2.50%, 2 c.c.	42.0	2
	NaCl 0.20%, 1 c.c.	8.0	1
	" 1.00%, 1 c.c.	10.0	1
	" 5.00%, 1 c.c.	14.0	1
	" 25.00%, 1 c.c.	17.0	1
	" 0.20%, 3 c.c.	11.0	1
	" 1.00%, 3 c.c.	14.0	1
	" 5.00%, 3 c.c.	17.0	1
	" 25.00%, 3 c.c.	24.0	1
B.....	HCl 0.50%, 1 c.c.	2.5	2
	" 1.00%, 1 c.c.	7.0	4
	" 2.50%, 1 c.c.	13.0	2
	" 5.00%, 1 c.c.	17.0	2

to normal (about 1 drop per minute). Table VII. shows the results of these tests. In no single case were the reactions proportional to the square root of the stimulus intensity. In the majority of cases the range of variation of secretion for different intensities is less than would be expected from Zebrowski's formula. Weber's law of constant increment seems to express the results more exactly, but the control of stimuli is not accurate enough for the computation of any

definite ratio. The technique employed is subject to almost all the objections outlined above and the experiments are reported in their present form only because they suggest that with an adequate technique a very accurate correlation of the intensity of stimulus and reaction may be demonstrated.

Stimulation of Restricted Areas in the Mouth.—The intensity of reaction to stimulation of restricted areas of the mouth has been investigated only by Heyman,[1] working with the dog. His results show a differential sensitivity of different areas of the mucosa to mechanical and chemical stimuli, with considerable variation between different dogs; a variation which corresponds to the different types of distribution of taste buds in man. His original publication is not available but it seems that only gross areas were stimulated.

In man a rather close restriction of stimulation to individual papillæ is possible so that a comparative study of the effect of different chemicals upon the end organs of the same region may be undertaken. Some preliminary tests to this end have been completed, the following technique being used.

The surface of the tongue was mapped out roughly and a regular series of movements of the tongue was adopted in order to control the non-gustatory stimuli. Before each stimulation the mouth was cleared of saliva, the tongue protruded as far as possible without strain, and the surface of the tongue was wiped from tip to base with a soft cotton cloth to erect the papillæ and remove adherent saliva. The taste substance was then applied to individual papillæ in the usual manner with a camel's hair brush. The tongue was next retracted and held depressed so that the taste substance was not spread by contact with the palate. After one minute the mouth was rinsed with 3 c.c. of water and the next test was delayed until the rate of secretion returned to normal.

The most extensive tests were carried out with three points on the dorsal surface of the tongue. These were:

[1] Cited from Babkin ('14).

(1) a group of three filiform papillæ on the right margin of the tip; (2) two fungiform papillæ just to the right of the mid-dorsal line, 5 cm. from the tip; (3) one circumvallate papilla on the left at the base of the tongue. The quantities of secretion obtained after stimulation of these areas are given in Table VIII. In the tests the rate of secretion before

TABLE VIII

THE QUANTITY OF SECRETION OBTAINED FROM THE LEFT PAROTID GLAND AFTER STIMULATION OF THE AREAS NUMBERED IN THE TEXT

The average numbers of drops obtained in the two minutes preceding and the two minutes following the application of the stimulus are given. The last column shows the relative increase in secretion resulting from the stimulus in terms of the increase produced by the same stimulus applied to papilla 1. Figures are based on the averages of five trials.*

Stimulus	Papilla	Drops Before Stimulation	Drops After Stimulation	Relative Increase
Water	1	3.7	4.0	1.0
"	2	4.6	5.6	2.6
"	3	3.7	4.7	3.4
HCl 10.00%	1	3.3	8.6	1.0
" "	2	3.2	12.7	1.8
" "	3	3.8	15.8	2.0
Cane sugar 20.00%	1	3.9	4.4	1.0
" " "	2	3.6	5.1	3.2
" " "	3	3.6	6.9	7.4
NaCl 10.00%	1	3.7	6.7	1.0
" "	2	3.2	8.7	2.5
" "	3	4.2	9.4	1.5
Quinine 0.2%	1	3.3	3.6	1.0
" "	2	2.3	3.3	4.8
" "	3	2.6	7.3	20.0
Faradic stimulation	1	1.5	8.5	1.0
" "	2	1.0	4.0	0.47
" "	3	1.5	4.5	0.53

stimulation varies from 1.3 to 2.3 drops per minute. Where the stimulus has little effect the initial rate affects the results considerably and for this reason I have used the increase in rate rather than the absolute secretion in comparing the excitability of different areas. The data are not extensive enough for certain conclusions but suggest that the tip of

* In computing these ratios the percentage increase over the initial rate of secretion has been taken as a basis. It is not certain that this method is justified, since there is some evidence that the amount of secretion given in response to a stimulus is independent of the rate of secretion of the gland before the stimulus is applied. The absolute amount of secretion after stimulation may be a more accurate measure of the effectiveness of the stimulus.

the tongue is relatively more sensitive to water, acid, and salt than to other gustatory stimuli; that the base of the tongue is relatively most sensitive to sugar and quinine; that the fungiform papillæ are most readily stimulated by salt. In the case of all but protopathic stimulation, however, the proximal regions of the tongue excite a greater secretion than the distal, irrespective of the quality or intensity of the stimulus. The effect of acid upon other parts of the mouth was tested by the same method. Stimulation of the hard palate, cheeks, lips, and uvula with acid excites no stronger secretion than is obtained with water. The soft palate is considerably more excitable to acid than to water.

The Rate of Recovery of the Gland from Excitation

The time required for recovery from stimulation varies with the intensity of stimulation. Table IX. shows the number of drops of saliva from the left parotid obtained in

Table IX

The Duration of Excitation of the Parotid

The amount of secretion, in drops, obtained during successive minutes after different intensities of stimulation is given. The stimulus was applied for one minute (1 in table) in each case, then rinsed from the tongue with water.

Stimulus	Successive Minutes									Total Secretion after Cessation of Stimulus
	1	2	3	4	5	6	7	8	9	
(Subject B)										
HCl 0.50%	3	0	0	0	1	0	0	—	—	1
" 1.00%	4	0	0	1	0	0	—	—	—	1
" 1.00%	5	2	0	1	0	0	—	—	—	3
" 1.00%	7	2	0	0	1	0	0	—	—	3
" 2.50%	8	4	2	1	1	1	0	—	—	9
(Subject L)										
HCl 0.25%	6	5	1	1	1	1	—	—	—	9
" 0.50%	14	4	2	1	1	2	—	—	—	10
" 2.50%	18	8	3	3	2	1	—	—	—	17
" 5.00%	31	7	3	3	2	3	—	—	—	18
" 0.50% 1 c.c.	12	1	1	3	1	1	—	—	—	7
" 0.50% 2 c.c.	14	5	3	2	2	1	—	—	—	13
" 0.50% 3 c.c.	17	4	2	2	2	1	—	—	—	11
NaCl 0.20%	5	1	2	2	1	0	—	—	—	6
" 1.00%	6	3	1	1	1	1	—	—	—	7
" 5.00%	8	4	2	1	2	1	—	—	—	10
" 25.00%	10	5	2	2	1	1	—	—	—	11
After 1 % HCl continuously for ten minutes	—	9	9	2	2	6	2	2	3	—

successive minutes during and after stimulation with salt and acid. In each test the stimulus solution was held in the mouth for one minute, then the mouth was rinsed with a pipette of water. The time required for the rate of secretion to fall to 1 or fewer drops per minute after the removal of the stimulus was roughly proportional to the intensity of stimulation. As a corollary of this the quantity of secretion after cessation of the stimulus is proportional to the intensity of stimulation (last column, Table IX.). After intense stimulation the heightened secretion may persist for ten or more minutes.

Fatigue of the Unconditioned Reflex

The possibility that fatigue of the direct reflex might interfere seriously with quantitative studies of the secretion led to a series of tests with continued stimulation. These were carried out as follows:

1. Two glass tubes were placed in the mouth in such a way that a constant stream of dilute hydrochloric acid could be directed against the soft palate and allowed to drain off from the tip of the tongue. The stimulating substance could thus be constantly renewed and the question of its dilution eliminated. With 0.25 per cent. acid continuous stimulation was given for ten minutes; with 1.0 per cent. acid for five minutes. The weaker solution excited in ten successive minutes a secretion of 18, 24, 18, 16, 15, 12, 11, 13, 12, 12 drops. The stronger solution gave in five successive minutes 28, 27, 30, 32, 30 drops. In this short time there is little evidence of fatigue. The series with the weaker solution is complicated by the fact that just before the end of the first minute the subject choked and swallowed some acid. The decrease in the rate of secretion following probably represents the recovery from this stimulation of the throat, rather than a fatigue of the reflex.

2. One cubic centimeter of 1.0 per cent. hydrochloric acid was placed in the subject's mouth at the beginning of each minute for 20 successive minutes. The quantities of secretion obtained during this time are shown in the following table.

Minute	Drops of Secretion	Minute	Drops of Secretion
1	10	11	8
2	9	12	8
3	8	13	10
4	9	14	9
5	10	15	9
6	7	16	10
7	8	17	8
8	10	18	10
9	9	19	9
10	9	20	9
Total	89	Total	90

The secretion obtained during the second ten minutes is practically the same as that during the first ten. There is no evidence of fatigue.

3. A 5.0 per cent. solution of sodium chloride was applied in the same way for ten minutes. The quantities of secretion in successive minutes were 6, 7, 6, 5, 5, 6, 5, 5, 5, 6 drops. There is here a reduction of only 7.0 per cent. from the average secretion of the first to that of the second five minutes.

Under the conditions of these tests the direct salivary reflex fatigues very slowly if at all.

Excitation of the Glands by Stimuli from Other Parts of the Digestive Tract

Jänicke ('78) and earlier workers believed that stimulation of the mucosa of the stomach excited salivary secretion. Buff ('88) failed to obtain any increase in secretion by stimulating the walls of the dog's stomach with acid introduced through a fistula and held that reflex excitation of the glands from the stomach does not occur. Ordenstein's data ('60) upon secretion measured for 27 consecutive hours shows some increase in glandular activity after the subject had eaten but the author does not discuss this point.

In the tests reported above upon the rate of secretion without extero-stimulation five subjects were examined immediately before and at intervals ranging from ten to sixty minutes after eating (Table I.). In every case the rate of secretion was greater after the meal than before. Stimulation

from particles of food remaining in the mouth was excluded, leaving the alternatives of stimulation from the stomach and intestine or persistent reaction to the long-continued oral stimulation in eating as possible explanations of the heightened rate of secretion. The latter seems to be excluded by the following observation.

The rate of secretion of the first subject recorded in Table I. was tested without extero-stimulation for fifteen minutes and found to be constant at 3.60 c.c. per hour. The subject then chewed 'Zwieback' for fifteen minutes without swallowing any of it, then cleared the mouth of adherent particles and returned to the apparatus. His rate of secretion during the following twenty minutes was found to be 3.60 c.c. per hour, exactly the same as before the oral stimulation. From this it seems that the increase in secretion following a meal is not the result of oral stimulation but is a reflex from some other part of the digestive tract.

The Effect of Olfactory Stimulation

The fact that the odor of food is sufficient to produce salivation has been commented upon frequently (Babkin, '14, p. 24) but I have been unable to find record of any experiments upon the direct reflex to odors in man. Zeliony[1] after ablation of the cerebral lobes of the dog was unable to obtain any glandular reaction to odors; a result which favors the view that the secretion observed by other investigators was a conditioned reflex.

The reactions of the human parotid to odors have been tested with several subjects. The results of tests with three of these are given in Table X. The subjects, with eyes closed, were stimulated for thirty seconds with each of the different odorous substances listed in the table and asked to identify the odors. The stimuli were given at intervals of six or more minutes, and the numbers of drops of saliva obtained during the three minutes preceding and the three minutes following stimulation are compared in the table.

In no case did any marked increase in secretion follow the

[1] Cited from Babkin ('14).

TABLE X

THE EFFECT OF OLFACTORY STIMULATION UPON THE SECRETION OF THE PAROTID GLAND

The total numbers of drops secreted during the three minutes preceding and the three minutes following stimulation are recorded. The stimuli were applied for 30 seconds.

Odorous Substance	Subject H		Subject B		Subject L	
	Before	After	Before	After	Before	After
Oil of peppermint	2	1	1	2	4	6
" of bergamot	3	2	.....	.....	2	3
" of cloves	.....	.....	0	0	2	3
" of wintergreen	.....	.....	.....	.....	2	2
Ether	1	2	.....	.....	4	3
Chloroform	.....	.....	1	1	.....	.....
Gum camphor	2	1	1	1	3	2
Amyl alcohol	.....	.....	2	1	2	6
Ethyl acetate	.....	.....	1	1	1	2
Ethyl alcohol	.....	.....	.....	.....	3	3
Asafetida	1	1	.....	.....	3	3
Butyric acid	1	2	1	1	2	2
Iodine	.....	.....	.....	.....	2	2
Cider vinegar	2	1	2	0	.....	.....
Fresh toast	2	1	3	1	2	2

stimulation. Amyl alcohol and oil of peppermint seemed to accelerate secretion but both irritate the mucosa of the pharynx, the former producing coughing, and the reaction is probably to this rather than to the odor. The range of odors is fairly broad and the experiments seem to prove that there is no unconditioned reflex secretion to olfactory stimulation.

INHIBITION AND REINFORCEMENT OF SECRETION

The data of Aschenbrandt ('81) upon salivary secretion after irritation of the conjunctival sac and Pawlow's observations ('78) upon inhibition of secretion by injury to the viscera in the dog have been disputed by Buff ('88). He himself lays great stress upon movements of the body as excitants of salivary secretion but gives no experimental evidence in support of his view. The statements of these men and the experiments of Brunacci and DeSanctis ('14), which will be considered later, constitute the only data available upon the indirect modification of the unconditioned reflex.

The series of tests summarized in Table XI. were carried out to test the effect of muscular activity upon the secretion of the parotid. Three types of activity were used, violent effort, rapid movement, and prolonged strain. In each case there was an inhibition of secretion during activity. During activity of this sort movements of the tongue and throat are largely inhibited, but such movements have normally very

TABLE XI

THE INFLUENCE OF MUSCULAR ACTIVITY UPON THE SECRETION OF THE PAROTID

Subject L

Stimulus	Average Drops of Secretion per Minute	
	Left parotid	
Subject lifted and held 50 pound weight above his head.		
Before exertion, 4 minutes	0.75	
During " 2 "	0.00	
After " 3 "	1.25	
"Setting up exercises"		
Before exertion, 3 minutes	1.25	
During " 5 "	0.40	
After " 3 "	1.00	
Arms held extended	Right parotid	Left parotid
Before exertion, 3 minutes	Right 2.0	2.3
During " 5 "	0.6	0.6
After " 3 "	1.6	1.6

little effect and it seems improbable that the suspension of secretion is due wholly to the change in the stimuli coming from the mouth. There seems to be an active inhibition of secretion during violent muscular effort.

A further series of tests was carried out with violent protopathic stimulation. The subject's finger-tips were placed against a knife electrode and a faradic current, strong enough to induce profuse perspiration, was directed through the fingers. The rate of secretion with and without faradic stimulation was determined. Brunacci's technique was then adopted, the subject being given 1 c.c. of 0.20 per cent. hydrochloric acid in the first second of each minute during the experiment. The reaction to the acid with and without faradic stimulation was determined. In one instance tickling of the subject's nose and lips was substituted for the faradic

stimulation. The results of these tests are shown in Table XII. The protopathic stimulation in every case led to a reduction in the rate of secretion. In test II. (Table XII.) complete recovery from the depression did not take place during the five minutes following the faradization, although the rate of secretion increased slightly with the cessation of

TABLE XII

THE EFFECT OF PROTOPATHIC STIMULATION UPON THE RATE OF SECRETION

The rate was determined before, during, and after intense protopathic stimulation continued for the time intervals indicated. In tests II, III, and IV one cubic centimeter of 0.20% HCl was given at the beginning of every minute.

Stimulus	Average Drops per Minute	Duration of Test, Minutes
Test I.		
Normal rate without stimulation	1.00	10
With faradic stimulation of fingers	0.75	10
Test II.		
(One c.c. of HCl at the beginning of each minute)		
Before faradization	12.30	4
During "	8.60	5
After "	9.20	5
Test III.		
Before faradization	11.80	11
During "	9.00	10
Rest for ten minutes		
After faradization	12.10	7
Test IV.		
Lip and nose tickled with a feather		
Before stimulation	12.10	7
During "	7.60	5

stimulation. This is not surprising, however, since the electric stimulation was severe, leaving the subject badly shaken. A ten minute rest, test III., resulted in complete recovery of the normal glandular activity.

Where the acid was given continuously the possibility of fatigue of the direct reflex must be considered. The data given on pages 480–481 show that within the time-limits of this experiment the direct reflex does not fatigue. Moreover, the change in the rate of secretion at the beginning of faradic stimulation was not gradual, as would be expected in fatigue, but abrupt. This is shown by the following figures from tests III. and IV.

	Drops Secreted in Last Three Minutes before Stimulation			Drops Secreted in First Three Minutes during Protopathic Stimulation		
Minutes	1	2	3	1	2	3
Test III.....	15	12	13	8	9	9
" IV.....	9	13	13	3	8	8

A serious defect in these experiments arises from the fact that the protopathic stimulus modifies the movements of the mouth and may prevent the usual distribution of the gustatory stimulus. The subject was warned to keep the distribution of the acid on the tongue uniform, but there is no certainty that this was done. Where rather large quantities of concentrated solution are used this source of error is certainly less important than where threshold intensities are used as in the experiments of Brunacci and DeSanctis reviewed below. The results of the tests with protopathic stimulation are consistent and it seems probable that there is an actual inhibition of secretion with very intense stimulation.

The Influence of Mental Work and Emotion upon the Rate of Secretion

Brunacci and DeSanctis ('14) have studied the effect of mental work upon the secretion of the parotid, finding a smaller quantity of secretion during activity than during repose. I have been unable to verify this result and believe that the apparent inhibition resulted from the technique used by these investigators. They stimulated their subjects once per minute with a very dilute solution of acetic acid and recorded the resultant secretion when the subjects were at rest and when they were translating from a foreign language or computing. A diminished secretion during mental activity was interpreted as evidence for inhibition. The importance of the distribution of the stimulus solution in the subject's mouth has been emphasized already. Any distraction may alter this distribution, which depends largely upon the movements of the tongue. The solutions used by Brunacci and DeSanctis were near the threshold intensity and there is no evidence from their experiments that the reduction of secretion was not due to a limited distribution of the stimulus solution when the subjects were occupied.

The following experiment shows an excitatory rather than an inhibitory effect of mental work upon the normal secretion of the gland. The subject was required to square three-place numbers without visual assistance for 20 minutes, to remain quiet for 20 minutes, and then to resume computation for 20 minutes more. The intensity of concentration is assured by the fact that the subject, who had had no experience with this type of computation, returned correct answers to three of twelve problems and made errors of only one figure in five other products. The average rates of secretion obtained were:

During first period of multiplication	1.80 drops per minute
During period of rest	1.23 " " "
During second period of multiplication	1.88 " " "

The rate of secretion during each of the periods was almost constant. An unmistakable increase in secretion resulted from the intense mental application. Similar, but less pronounced results have been obtained with other subjects having a lesser rate of secretion without extero-stimulation. In one case reduced secretion appeared during computation. This subject obviously used the fingers largely in computation while the others seemed to rely wholly upon the speech mechanism. This suggests a possible correlation between the implicit system employed and the effect of mental work upon secretion.

The inhibition of salivary secretion during fear has been noted frequently but there is no definite evidence as to the effects of other types of emotion. Colin ('45) states that salivary secretion is increased during sexual excitement. Von Bechterew ('08, p. 452) says: "Every pleasant sexual excitation is undoubtedly accompanied by salivary secretion; it is questionable only whether this is a reflex from the genitals or (as seems to me more probable) a psychic effect." Since a certain grade of erotic emotion is easily aroused in the laboratory it seemed worth while to test the extent to which the statements of these authors, who give no experimental evidence, can be applied to the parotid gland. For the stimulus to sexual excitement a collection of pornographic

literature and pictures was used. The rate of secretion of the subjects while quiet or reading indifferent material was determined. They were then given the erethitic material and the rate of secretion while this was examined was determined. Finally a second determination of the normal rate was made. Table XIII. shows the effect of the erotic emotion. In every instance it resulted in a reduction of the rate of secretion. The exciting effect of the material used has been tested in other experiments and there is no doubt of its erethitic nature. The tests seem extensive enough to establish the inhibitory effect of erotic emotion.

TABLE XIII

THE INHIBITORY EFFECT OF EROTIC EMOTION

The average secretion in drops per minute is recorded. The subjects read indifferent material for 20 minutes or more (first column), then examined the erethitic material for ten minutes (second column).

Subject	Secretion with Indifferent Material. Drops per Min.	Secretion with Erethitic Material. Drops per Min.
B	0.36	0.11
B	0.77	0.00
T	0.80	0.36
M	0.20	0.10

A second effect of this emotion seems to be an almost complete inhibition of the swallowing reflex. The secretion accumulates in the mouth and subjects have been seen to drool saliva while reading the pornographic literature although the secretion of the parotid glands was partially suppressed. This probably accounts for the statements of Colin and von Bechterew, whose observations do not seem to have been made upon isolated glands.

It has not been possible to obtain strong emotion of other types in the laboratory. In one instance, when a long series of tests was made with a disagreeable mixture of hydrochloric acid and sugar, the subject became rebellious and, when the experimenter insisted on continuing the work, angry. The reactions of the parotid became less intense and quite irregular under these conditions.

Conditioned Reflexes Appearing without Training

None of the students of human parotid secretion has been able to demonstrate conditioned reflexes. The reason for this is, perhaps, that they have made no attempt to reproduce in the laboratory the environment in which the subjects were accustomed to obtain food. Early in my own experiments it became evident that no increase in secretion followed the mention of food. As it seemed possible that lack of real hunger was responsible for the absence of secretion the first test for the conditioned reflex was made under rather severe conditions. The subject abstained from food for three days, the drainage tube was then placed over the left Stenson's duct and a list of fifty-three words, fifteen of which were names of foods, the others indifferent, was read to him. The words were given at two-minute intervals and the secretion recorded in drops per minute. The average secretion following the names of foods was 2.00 drops per minute; following the indifferent words it was 2.10 drops per minute. There is absolutely no evidence of a conditioned reflex.

With the sight of food as a stimulus quite different results were obtained. In this test the subject abstained from food for twenty-four hours and was then shown a variety of foods. No increase in secretion appeared with the sight of food. The subject was then allowed to eat a single raw oyster, rather heavily seasoned with paprika. An immediate change in the salivary reaction to the sight of food followed. This may be illustrated in detail by a test with a bar of almond chocolate, which shows the extreme sensitivity of the reflex. In the following table the number of drops of saliva secreted during successive minutes is given on the right, the conditions of stimulation are given on the left.

No extero-stimulation	1
	0
Chocolate placed in subject's hand	4
	3
	4
Subject smelled chocolate	5
Brought chocolate to lips but kept mouth closed	9

Held chocolate at arm's length 4
3
3
Told to eat but stopped as chocolate reached lips 7
6
2
Chocolate snatched away 0
0
3
2
2
1
Chocolate given back and held at arm's length 4
3
4
3
Chocolate snatched away 1
1
Chocolate given back 4
2
4
Chocolate eaten 32
13

Like results were obtained in other tests but varied with the particular food used. The effects of handling different food-stuffs are shown in Table XIV. Where no secretion was excited by the sight of food, raising the food toward the mouth was sufficient to excite secretion, except in the case of the peppermint which the subject dislikes.

TABLE XIV

EXCITATION OF THE PAROTID BY VISUAL AND OLFACTORY STIMULATION FROM FOOD

The subject was forbidden to eat. Secretion without stimulation was recorded for two minutes, food was then given to the subject and the secretion recorded for four minutes more. The quantities are given in drops.

Stimulus	Successive Minutes					
	Before Stimulation		During Stimulation			
	1	2	3	4	5	6
Peeling orange	2	1	2	1	1	1
Holding plate of oysters	1	1	1	1	1	1
Holding peppermint candy	1	1	0	0		
Peeling banana	1	1	2	3	3	1
Holding chocolate	1	0	4	3	4	4
Holding glass of beer	1	1	3	2	2	1

Tests involving the same movements of hands and mouth as those used with the food but in which inedible substances were held resulted in no increase in secretion, so that it seems quite certain that the results obtained with food substances are due to conditioned reflexes to the visual and olfactory characters of the food.

During the experiments reported on pages 473–477 the formation of conditioned reflexes to the sight of the bottles of acid and other objects used in giving gustatory stimuli was noted but discussion of these must be postponed to a later paper.

Summary

The experiments reported form a preliminary survey of the conditions affecting the secretion of the parotid gland. Only the direct reflex has been considered extensively but the data obtained upon this phase of secretory activity furnishes a basis for an investigation of some of the acquired reflexes of the human autonomic nervous system. While all classes of stimuli which may affect secretion have not been tested it is probable that those employed embrace the ones which are most influential and which might enter as conflicting elements into studies of acquired reflexes. Chemical analysis of the saliva has not been possible but the first tests of conditioned secretion may be restricted advantageously to quantitative experiments which will not be affected seriously by this lack.

The experiments thus far reported seem to justify the following conclusions:

1. Direct reflexes of the parotid gland are excited by mechanical, chemical, and protopathic stimulation of the oral mucosa. Lack of an adequate method of limiting the distribution of chemical stimuli has prevented accurate quantitative experiments.

2. There is probably no direct reflex to thermal stimuli unless they are of protopathic intensity.

3. The secretion produced when a foreign object is chewed involves a specific reaction to a complex group of stimuli.

4. The reaction of the parotid is most intense when the homolateral mucosa is stimulated.

5. The quantity of secretion varies with different chemical stimuli applied to different parts of the mucosa but is usually greatest when the proximal region of the tongue is stimulated.

6. The presence of food in the stomach excites secretion.

7. There is no direct reflex to olfactory or to ordinary visual, auditory, or tactile stimulation.

8. Parotid secretion is partially inhibited by violent muscular activity. Mental work (involving movements of the tongue and throat?) increases the secretion.

9. Erotic emotion reduces the quantity of secretion.

10. Reflex secretion is excited by the sight and odor of food but is conditioned by hunger, by the previous experience of getting food under the conditions of the experiment, and by complex emotional factors which have not been analyzed.

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POSITIVE ACCELERATION IN IMPROVEMENT IN A COMPLEX FUNCTION

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Concerning the general characteristics of the practice curve in most mental and motor functions which lend themselves to psychological investigation, there can be little doubt. Measurements of gain in efficiency have been made in tests which vary from those of distinct simplicity, such as rate of tapping, tossing balls, marking letters, to those which present more complex mental and motor adjustments of which illustrations could be found in typewriting, telegraphic sending and receiving, and mental multiplication.

In studies of such functions, made at various places, in some cases upon numerous individuals, certain peculiarities of the curve are revealed; namely, a rapid initial rise, under the usual conditions of practice, following this a gradual decline in the rate of improvement, until a point is reached when no amount of further practice under normal circumstances will result in any increase in ability. In other words, there is a continuous decrease in the rate of improvement indicating the entrance of the law of diminishing returns, a decrease which is more rapid at the beginning of the work than in its later stages. Some curves obtained in peculiar functions such as tossing balls, which do not appear to follow this law, can be brought under the general case when the basis of scoring is altered, so as to make a gain in score at the end of the practice period more adequately represent the corresponding gain in efficiency. In fact it may be said that to a certain extent one of the best tests of a fair system of scoring in the general run of functions, is to inquire whether the curve obtained shows the general characteristics of a rapid initial rise followed by negative acceleration in improvement which eventually brings the curve parallel to the time axis.

In this paper attention is directed to the first part of the practice curve which, in the simple and even in the more complex functions that have thus far been investigated, has shown a decreasing rate of improvement from almost the commencement of the work. That is, if we take a simple test, such as tapping, it is possible that while the subject is adapting himself to the work he may for a very short time show a positive acceleration in improvement, but if work is continued this soon gives way to a pronounced negative acceleration which brings the efficiency to its physiological limit. In a simple function this period of adaptation is too brief to admit of measurement, in the case of an adult, but there can be little doubt that it is present and would reveal itself if the gain in efficiency could be measured over short enough periods of time. On account of this rapid adaptation of previous powers to the task in hand, it has been assumed that negative acceleration in improvement is a universal law for all practice curves.

In the case of improvement when very young children are examined, the same type of curve would not necessarily be expected; it might be supposed that for a longer period the more practice the child had, the greater would be the rate of improvement, for each habit acquired in the process would make it easier for the next habit to be gained; in this way a curve indicating a law of increasing returns would be obtained, the curve being convex to the time axis. As practice is continued, the positive acceleration would give way to negative acceleration, and eventually the physiological limit would be reached. That is, the curve would consist of four parts: (1) the first part where there is a positive acceleration in improvement; (2) the second part, a straight line, where the acceleration is zero; (3) the third part, characteristic of the adult curve, where a negative acceleration in improvement is found; (4) the straight part of the curve parallel to the time axis where there is no further improvement.

In the case of adults, if measurements of improvement in suitable functions were made, negative acceleration might prove to be far from a general rule in learning. In the content subjects such as history or geography it is possible that each

fact acquired makes it easier to acquire other facts and to fit them into a system, so that day by day, on any reasonable basis of scoring the law of increasing returns would make itself evident. Practice in the acquirement of a foreign language or in acquiring skill in shorthand would probably show similar results. In so far as experiments have been made upon improvement in these complex functions they fail, perhaps owing to the lack of sufficient subjects, to give any indication of positive acceleration, but they reveal a much greater tendency towards zero acceleration than the simpler functions which have been so closely examined in the psychological laboratory.

It would appear then if evidence of the law of increasing returns is to be obtained investigation should be confined to those functions in which improvement extends over very long periods of time, and which initially are very complex. Such a test as Arai[1] underwent, in which mental multiplication of four place numbers by four place numbers was necessary might be repeated using more subjects; for in a test of this type, the period of adaptation to the work must be more prolonged than in a simple test. In fact Arai's scores at the commencement of the work do show a minimum of negative acceleration, to such an extent that if the results are pressed to their limit they might be used as evidence in the case of a single subject of the entrance of very slight positive acceleration in improvement. Such an experiment would be difficult to repeat on account of the time involved, the closeness of the work, and the uselessness of the exercise and the product. It is therefore essential to seek other functions, which may be equally or more complex, but which admit of measurement without the necessity of producing elaborate and artificial conditions.

In the ordinary course of instruction in telegraphic operating a study of the initial rate of improvement would undoubtedly yield very interesting results, but here it is difficult to obtain the necessary facilities. The one study that has been performed upon this subject by Bryan and Harter[2]

[1] Arai, T., 'Mental Fatigue,' Teachers College, Columbia College Contributions to Education, No. 54.

[2] Bryan, W. L., and Harter, N., 'Studies in the Physiology and Psychology of the Telegraphic Language,' *Psychological Review*, Vol. 4, pp. 27–53, and Vol. 6, pp. 345–375.

does not indicate that with the two individuals involved there was anything more than a prolonged period of steady improvement, that is, the acceleration was zero; certainly it gives no evidence of positive acceleration as a common method of learning. Typewriting is another example of a function which requires a long period of practice before the limit of improvement is reached. Both methods of learning, the sight, and the touch method, have been investigated by Book,[1] Rejall, Hill, and Thorndike.[2] A short description of Book's experiments will suffice to summarize the general conclusions. Using the sight method with two subjects, Book found the usual type of improvement curve, a rapid initial rise, throughout which may be traced the negative acceleration, as is shown by the curves for the two individuals being concave towards the time axis. Using the touch method, which in its initial stages is more difficult, a different type of curve was obtained, in which the rise is less rapid; negative acceleration does not appear pronouncedly, the general rate of improvement being steady for the first ninety hours in the case of one of the subjects. With the other subject, although negative acceleration is less pronounced than when the sight method was used, the curve is distinctly concave towards the time axis. Rejall, Hill and Thorndike obtained the same results. In all these studies the small number of subjects makes general conclusions impossible, for individual differences in improvement are just as great as in static efficiencies.[3] If general laws are to be deduced, or if anything approaching evidence of the methods by which we learn is to result, these experiments must be performed upon numerous subjects under the same conditions, for there is no guarantee that the few subjects already investigated are representative.

Fortunately under the ordinary conditions of school work such a study is possible; typewriting as taught in the various

[1] Book, W. F., 'The Psychology of Skill with Special Reference to its Acquisition in Typewriting,' University of Montana Publications in Psychology: Bulletin No. 53, Psychological Series No. 1.

[2] Rejall, A. E., and Hill, L. B., and Thorndike, E. L., 'Practice in the Case of Typewriting,' *Pedagogical Seminary*, Vol. XX, No. 4.

[3] Chapman, J. C., 'Individual Differences in Ability and Improvement,' Columbia University Contributions to Education, No. 63.

business schools and high schools of commerce furnishes conditions, which while in no way equal to the exactness of laboratory experiments are yet sufficiently under control to be serviceable. Moreover, the subjects who may be as many as desired, are working under normal conditions, which from the standpoint of the psychology of normal learning is more interesting than the work done under the trying conditions of the psychological laboratory. The nearer an approach is made to measuring improvement under the natural conditions of school, the more likely are the results to give a useful idea of the general nature of changes in the rate of improvement.

The present research was undertaken with a double object: (1) to obtain evidence with a view to a systematic study of the psychology of skill from the objective standpoint. (2) To investigate the rate of improvement of the subjects, in this particular school, using this particular method of instruction, so as to establish norms by which the efficiency of other methods could be judged. The latter investigation has interest from the administrative standpoint; in the commercial schools of the country, various methods of instruction are employed; it is a matter of some importance to see which method yields the most satisfactory results. No attempt will be made in this paper to establish norms, except in so far as the particular curves selected at random indicate a general rate of improvement. The study is not yet complete for the practice of the subjects extends over two school years, and up to the present the writers only have the material of one year's work for the same subjects, the subjects who started typewriting exercise in September, 1914. Only one half of the improvement curve is as yet complete, but the results during the first eighty hours' practice are of sufficient interest to warrant special attention, as they illustrate very clearly important points in the learning process, which have not been emphasized and have even been overlooked in previous studies. In particular we shall consider the over-emphasis which has been laid on negative acceleration in improvement as an almost invariable accompaniment of extended practice.

The general method of the research was to test, each week

in the school year, the speed of a mixed class, ages 16–18, in typewriting. The material used consisted of extracts from Addison's 'Essays,' which were selected so as to be of approximately equal difficulty. This material was printed and on a certain day of the week administered to the whole school; the object being to copy as much of the material as possible in five minutes. Care was taken that the various sections who took the test early in the day did not communicate with the later sections. The copy each week was new, though being taken from the same author a similarity in style persisted. The following report from each individual taking part in the test was obtained, in addition to the extract that was typed in the five-minute period: (1) Hours practised since last test, (*a*) in school, (*b*) out of school; (2) gross number of words typed in five minutes; (3) number of errors in (*a*) words, (*b*) punctuation, (*c*) spacing; (4) net score on the basis of one point for each word, less one point for each error; (5) net score on the basis of one point for each word less five points for each error. Before the test started very careful inquiries were made to find whether the subjects had had previous practice in typewriting, if so, for how long, and what method of learning had been used. The results as recorded in this paper are worked out from scores on the basis of report (4), that is upon the total number of words attempted less one word for each error. The experimental errors and individual fluctuations are too great to justify the reduction of the scores to so fine a measure as number of strokes; the time that would be involved in such reduction would yield no adequate return.

When the research has extended over the two years devoted to type-writing there will result improvement curves for about fifty individuals, over a period extending from 20 to about 250 hours of practice. During this period except for rare absences each individual will have been tested at approximately three-hour intervals. This preliminary paper, however, will deal with only two sections, (1) those who, starting with 20 hours' practice, have now had about 80 additional hours; (2) another section, while starting with 75 hours of practice, have now had a further period of 90 hours.

Composite curves, unless the subjects have nearly the same initial ability and rate of improvement, are apt to lead to misunderstanding and to mask important effects which occur in the individual practice curves; for this reason in presenting the data of this study, individual cases will be cited, which may be regarded as typical of the general case.

Group Commencing Work with 20 Hours' Practice

Dealing with the section that had just commenced typewriting, it was not feasible to measure improvement from the very early hours, for in the touch method the attempt is first made to familiarize the learner with particular portions of the keyboard; so that the power of typing a continuous piece would be no test of improvement; in fact, even after ten or fifteen hours there would be a decided tendency if the basis of scoring was one point off for each word in which there was an error, for the score to be negative, that is, in the touch method, unless a certain proficiency is reached, work of any reasonable kind is out of the question. This would not apply to learning by the sight method, where accuracy and a steady improvement is the general rule. Whereas in the touch system certain elementary habit groups have to be formed before the individual can attain a positive score at all; to this extent the scale is inadequate, for a zero score need not represent the zero of typewriting ability. However, any other method of scoring unless we reduce to strokes correct, would suffer from greater disadvantages than this present method. It is perhaps legitimate to assume that an individual who on the average makes a mistake in each word has, from the practical standpoint, something which approaches zero ability in the trait. The scoring on the present basis has the great advantage of being straightforward, and the data are given in such form that the reader can work out the scores penalizing errors in any way that may seem more reasonable; no method of computation will effect the main thesis of the paper.

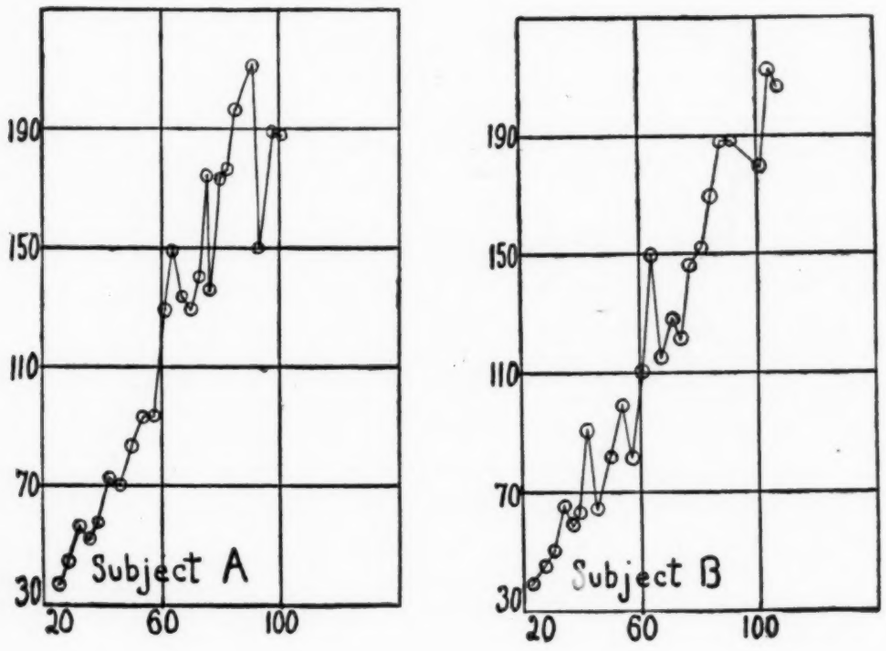
For convenience of presentation we have selected eight individuals at random from the group that has been measured while practicing over a period extending from 20 to 100 hours.

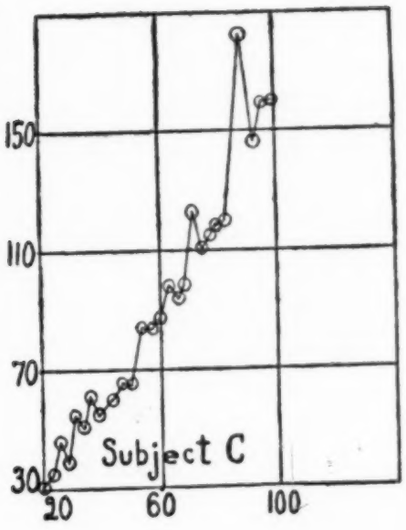
TABLE I

Subject *A*				Subject *B*				Subject *C*				Subject *D*				Subject *E*				Subject *F*				Subject *G*				Subject *H*			
Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score
25	38	1	37	23	43	4	39	20	31	0	31	20	48	2	46	20	20	0	20	20	41	0	41	20	50	6	44	22	43	1	42
28	44	0	44	27	46	1	45	23	35	0	35	23	56	1	55	23	23	0	23	23	53	0	53	24	59	2	57	26	40	0	40
32	56	0	56	30	52	2	50	26	47	1	46	30	79	3	76	29	38	1	37	27	74	3	71	27	71	1	70	29	62	1	61
35	56	4	52	34	66	1	65	29	40	1	39	36	60	2	58	34	32	3	29	30	67	0	67	30	68	3	65	33	85	1	84
38	62	5	57	37	60	1	59	31	56	1	55	38	74	0	74	38	54	3	51	32	82	3	79	32	77	1	76	36	80	2	78
42	75	2	73	39	67	4	63	34	52	1	51	42	79	1	78	42	59	0	59	34	84	2	82	35	89	2	87	38	97	5	92
46	76	6	70	42	93	2	91	36	61	0	61	45	87	1	86	48	68	2	66	36	97	0	97	37	122	3	119	41	112	6	106
50	86	3	83	45	67	3	64	39	55	0	55	48	63	1	62	52	53	2	51	39	82	0	82	40	86	7	79	44	91	3	88
54	99	6	93	50	83	1	82	44	60	0	60	52	92	1	91	58	89	4	85	43	104	0	104	45	91	5	86	49	96	2	94
57	93	0	93	54	102	3	99	47	65	0	65	55	102	1	101	63	119	7	112	47	132	2	130	47	107	3	104	52	124	6	118
61	132	3	129	57	83	1	82	50	65	0	65	58	93	1	92	68	106	4	102	51	128	1	127	50	108	3	105	55	99	4	95
64	152	3	149	61	116	5	111	54	84	0	84	62	119	1	118	73	106	2	104	55	161	3	158	54	130	4	126	59	125	14	111
67	145	12	133	64	155	5	150	57	85	1	84	66	149	1	148	76	133	2	131	58	159	2	157	57	132	4	128	62	134	12	122
70	130	3	127	67	125	10	115	60	90	3	87	69	132	2	130	80	148	2	146	61	149	2	147	59	138	4	134	65	139	8	131
73	142	2	140	71	135	7	128	63	98	0	98	72	152	0	152	84	141	5	136	64	168	1	167	62	139	2	137	68	138	11	127
75	176	2	174	74	131	10	121	66	95	1	94	75	144	2	142	88	123	0	123	68	178	3	175	65	124	2	122	71	137	9	128
76	139	4	135	77	156	10	146	68	98	0	98	78	162	4	158	93	156	3	153	71	185	0	185	68	138	2	136	75	140	7	133
79	175	2	173	81	161	9	152	71	123	0	123	80	162	4	158	97	217	5	212	74	225	3	222	71	145	5	140	78	162	8	154
82	180	4	176	84	177	8	169	74	113	2	111	83	171	3	168	100	186	6	180	77	201	2	199	74	142	2	140	81	152	9	143
85	198	2	196	88	196	8	188	77	118	3	115	86	199	9	190	106	210	1	209	80	231	3	228	77	151	1	150	84	161	6	155
91	216	5	211	91	200	12	188	79	120	2	118	89	204	2	202	112	216	4	212	83	216	1	215	84	151	3	148	87	164	13	151
93	152	2	150	96	250	6	244	82	120	0	120	92	234	4	230	118	188	1	187	86	233	1	232	87	146	4	142	90	170	8	162
98	197	8	189	101	187	8	179	88	186	3	183	97	213	1	212	134	209	2	207	91	211	4	207	92	154	2	152	95	202	7	195
100	195	7	188	104	223	11	212	92	148	2	146	101	236	3	233	...	...	...	...	95	225	4	221	95	171	2	169	98	168	9	159
...	....	....	....	107	215	9	206	95	162	2	160	104	204	4	200	...	...	...	...	99	214	4	210	...	...	...	...	101	177	7	170
...	....	....	....	....	....	....	....	97	161	1	160	107	264	3	261	...	...	...	...	102	229	2	227	...	...	...	...	102	173	8	165
...	....	....	....	....	....	....	....	....	....	....	....	110	279	5	274	...	...	...	...	105	209	5	204	...	...	...	...	105	175	10	165
...	....	....	....	....	....	....	....	....	....	....	....	114	240	0	240	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	....	....	....	....	....	....	....	....	....	....	....	119	236	1	235	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	....	....	....	....	....	....	....	....	....	....	....	124	218	2	216	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

In Table I the scores of these individuals are recorded on the basis described previously. The periods of time practiced are reduced to the nearest hour, as any finer scale would not be consistent with the observational error.

The data of these tables are presented in graphical form in the diagrams that follow; where the abscissæ represent the times of practice and the ordinates are the net scores.

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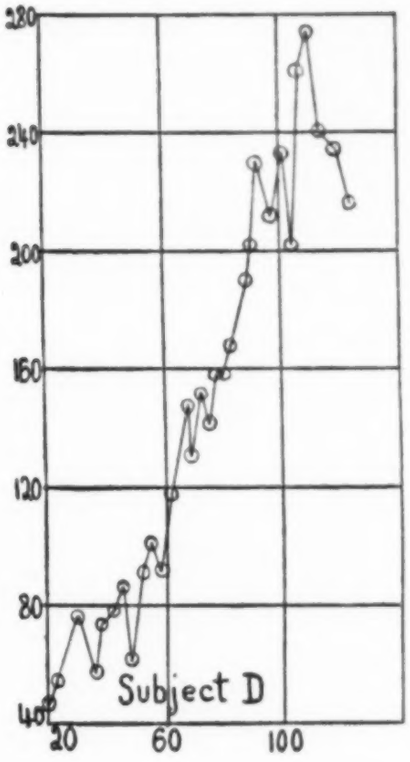
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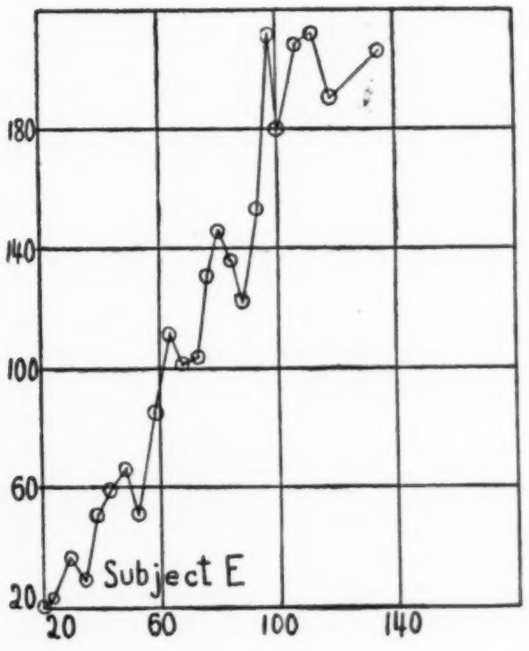
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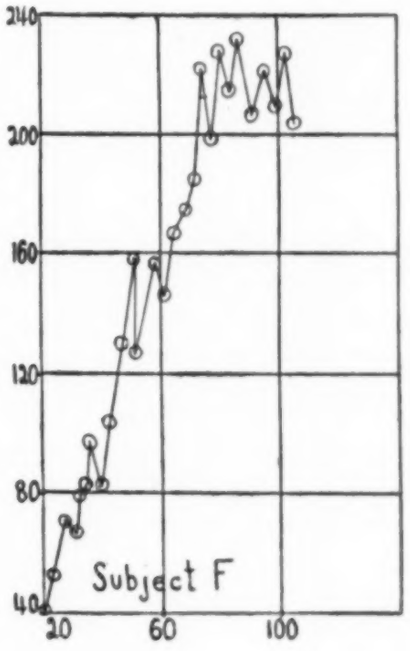
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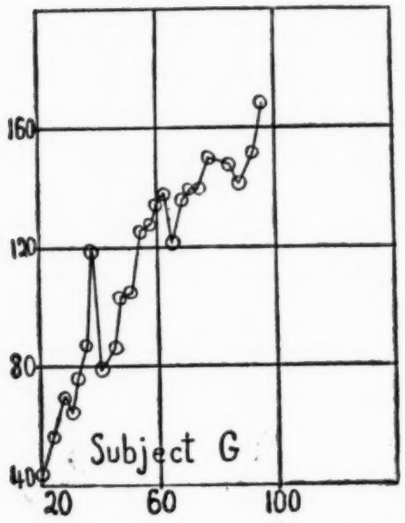
Subject F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Subject G
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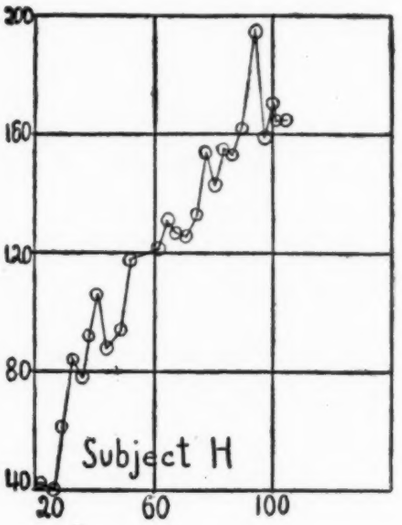
200
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Subject H
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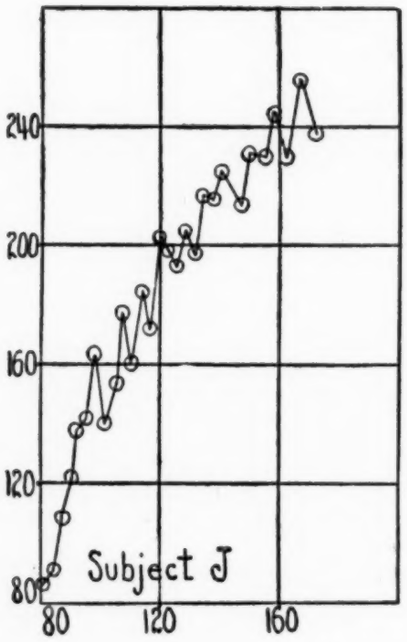
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Subject J
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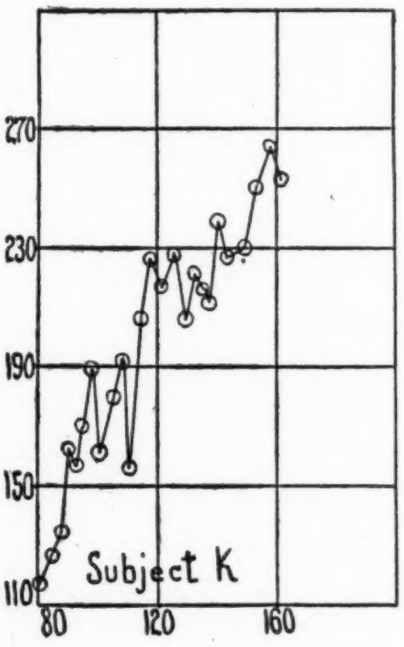
160


270
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190
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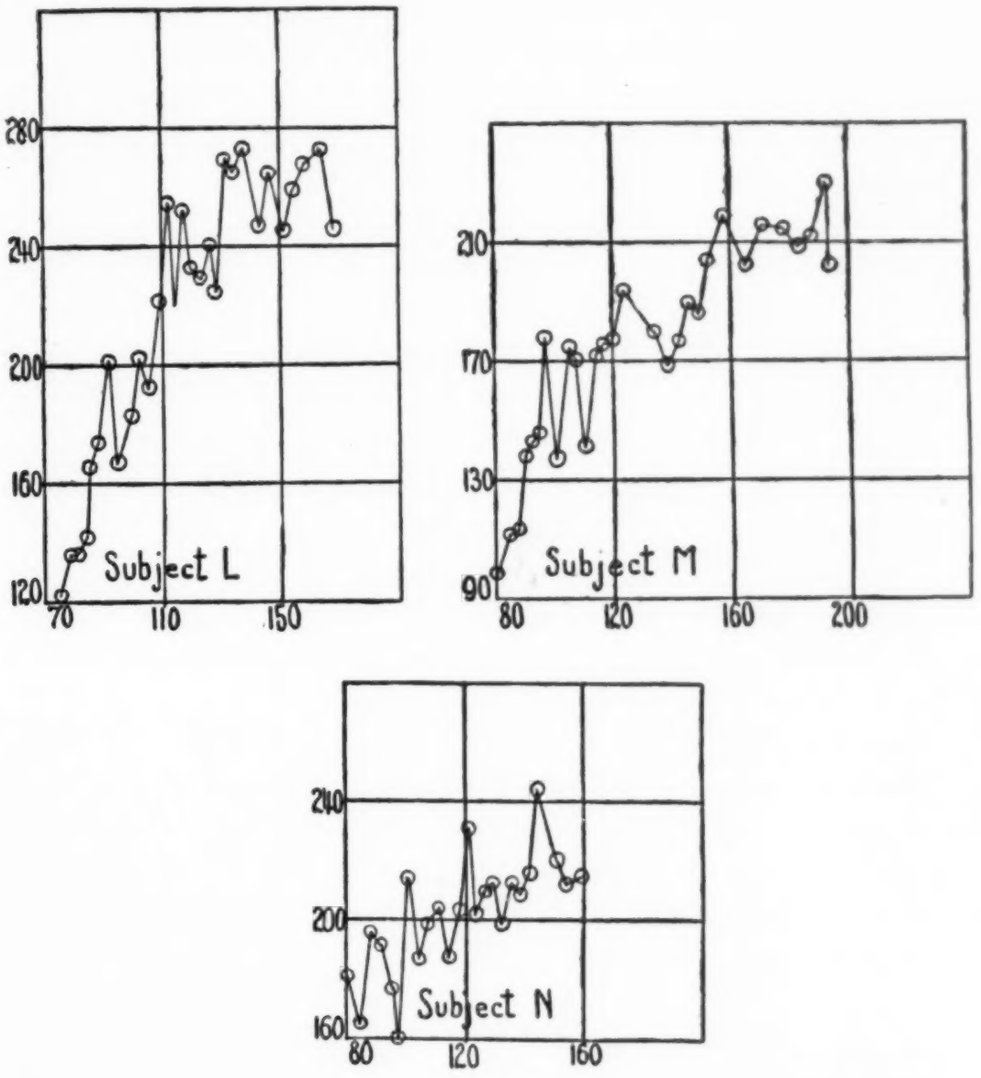
Subject K
80
120
160



The curves, for individuals measured over the 20 to 100 hours of practice show in the majority of cases striking evidence of the entrance of a positive acceleration in improvement in a motor function trained over a considerable period of time. The records were selected at random and only in the two cases shown (subjects *G* and *H*) was there any evidence of negative acceleration; in one case (subject *F*), a straight line has resulted, showing that the rate of improvement was steady over the period measured. In all the other cases (subjects *A* to *E*) positive acceleration appears. There is no need to enter into the reasons for this acceleration, they have been discussed shortly in the earlier parts of the paper. A priori consideration

would indicate that positive acceleration must be obtained in functions of great complexity, and this research reveals the fact that a common method of teaching touch typewriting, the Curry Method, has resulted in a type of improvement which theory would suggest.

Group Commencing Work with 75 Hours' Practice

It is interesting to compare the rate of learning of the earlier section with that of the later section. In the latter case the individuals had had approximately 75 hours of practice; as a consequence we might expect that the part of the curve which corresponds to the period of positive acceleration would have been passed. The curves obtained would therefore be concave to the time axis, as opposed to the earlier curves which are convex in that direction.

In the following table the results of five individuals (subjects *J* to *N*) selected at random are recorded.

The diagrams present the above tables in graphical form.

In these cases it will be seen that the typical adult improvement curves are obtained as the result of the entrance of negative acceleration with extended practice. The shape of these curves is in marked contrast to those of the earlier group where positive acceleration is present.

Summary

In this experiment it has been shown that over a period of practice of 60 hours, it is quite common for positive acceleration in improvement to take place when typewriting by the touch method is studied under school conditions. Measurements were made at weekly intervals of 100 individuals in the typewriting class of a school of commerce. Results selected at random from the group practicing for 20–100 hours show initial positive acceleration whereas for the group practicing 75–165 hours, the ordinary type of practice curve, indicating negative acceleration in improvement, is the general rule. While no claim is made that positive acceleration in improvement, over short periods of time, is universal in adult learning, yet in complex traits it is probably always present to a certain extent and must be considered in framing a psychology of skill.

TABLE II

Subject *J*				Subject *K*				Subject *L*				Subject *M*				Subject *N*			
Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score	Hours Practiced	Gross Score	Errors	Net Score
80	89	3	86	80	119	2	117	75	125	3	122	80	98	0	98	80	188	7	181
84	94	3	91	84	130	3	127	78	141	5	136	84	113	1	112	84	178	10	168
87	110	1	109	87	139	4	135	81	141	4	137	87	115	2	113	88	204	8	196
90	124	2	122	90	164	1	163	84	151	9	142	90	141	3	138	91	202	10	192
92	140	2	138	92	159	2	157	85	167	2	165	92	145	2	143	95	185	8	177
95	144	2	142	94	175	5	170	88	175	1	174	94	152	7	145	97	167	7	160
98	166	3	163	97	190	1	189	91	202	1	201	97	183	5	178	100	220	6	214
101	144	4	140	100	165	4	161	94	170	3	167	100	143	6	137	104	195	8	187
105	155	1	154	105	185	5	180	99	190	7	183	105	178	2	176	107	201	2	199
107	180	2	178	107	197	5	192	102	205	3	202	107	178	7	171	111	209	5	204
110	161	1	160	110	160	4	156	105	195	3	192	110	147	6	141	114	194	7	187
114	188	3	185	114	211	5	206	109	230	8	222	114	175	3	172	118	209	5	204
116	174	2	172	117	230	4	226	112	260	5	255	117	180	4	176	121	235	4	231
119	208	5	203	121	221	4	217	114	225	5	220	120	185	8	177	123	209	7	202
122	201	3	198	125	229	2	227	117	259	7	252	124	195	1	194	126	214	4	210
125	198	5	193	129	210	4	206	120	242	9	233	134	191	11	180	129	220	7	213
128	208	3	205	132	223	2	221	123	236	7	229	138	179	10	169	132	204	5	199
131	200	3	197	135	218	2	216	126	248	7	241	142	182	5	177	135	220	7	213
134	220	3	217	137	215	3	212	128	233	8	225	145	195	5	190	138	215	6	209
137	220	4	216	140	242	3	239	131	275	6	269	149	193	7	186	141	221	5	216
140	228	3	225	143	228	1	227	134	275	10	265	152	212	8	204	144	250	5	245
147	217	3	214	149	233	3	230	137	281	8	273	158	222	3	219	151	220	7	213
150	235	4	231	153	251	1	250	143	252	5	247	165	209	7	202	154	219	6	213
155	234	4	230	158	268	4	264	146	274	9	265	171	225	9	216	159	220	5	215
158	248	3	245	161	256	3	253	151	250	5	245	178	222	7	215	...	...	...	...
162	234	4	230	....	....	...	...	154	264	5	259	183	219	10	209	...	...	...	...
167	257	1	256	....	....	...	...	158	272	4	268	187	216	4	212	...	...	...	...
172	241	3	238	....	....	...	...	163	278	5	273	192	237	7	230	...	...	...	...
....	....	....	....	....	....	...	...	168	250	4	246	197	202	0	202	...	...	...	...

It is with pleasure that we record our obligations to the authorities of the West High School of Commerce of Cleveland for their courtesy in affording facilities for this research, and especially to Mr. James S. Curry for his valuable assistance in the administration of the tests.

THE INFLUENCE OF MENTAL AND PHYSICAL WORK ON THE FORMATION OF JUDGMENTS IN LIFTED WEIGHT EXPERIMENTS

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1. Introduction.

The controversy concerning the effect of mental and physical work upon cutaneous sensitivity is so well known that we may pass over it without going into detail. Griesbach (14, 15)[1] was the first to claim that the two-point threshold was increased by mental work and hence suggested this as a measure of mental fatigue. This method found many adherents, among whom we may mention Eulenberg (7), Heller (18), Joteyko (19), and Vannod (34). The method was revived by Binet (3) and Schuyten (30, 31, 32), and among the later experimenters who have obtained confirmatory results we may mention some further experiments by Griesbach (16) and investigations by Abelson (1), Bonoff (5), Chabot (6), Sakaki (28) and Schlesinger (29).

The method, however, has been subjected to a great deal of criticism from both theoretical and experimental points of view. Kraepelin (20, 21) was the first critic and he was followed in rapid succession by Leuba (22), Germann (10), Gineff (11) and Bolton (4). Some of the other investigators who discredit the findings of Griesbach and his followers are Meumann (25), Ritter (27) and recently Martyn (24). These

[1] The numbers in parentheses refer to the references at the end of this paper.

investigators not only failed to confirm the applicability of the method but they presented certain theoretical criticisms of a telling nature. Chief among these, perhaps, is the difficulty of æsthesiometric determinations and the difficulty of exact and constant stimulation even with the newer forms of instruments now in use. Bolton in particular shows the complexity of the problem and the large number of factors involved. The small number of determinations on each individual, made by the earlier investigators, has come in for criticism. Both the matters of the technique and the number of determinations were rectified, to a certain extent, by some of the later investigators who obtained confirmatory results.

Martyn, the most recent investigator, who had employed the method, criticizes it and her own results by asserting that the spatial threshold is not constant enough for use for this purpose. One reason is that the subjects experienced difficulty in maintaining the same judgment with regard to the threshold of 'twoness.' This would seem very probable because there can be no doubt that the old categories of one-point, two-point and doubtful by no means exhaust the psychological possibilities in investigations of this sort. Recently Gates (9) in studying the sensitivity of this modality, had to admit nine categories of judgments, namely: point, point-circle, circle, circle-line, line, line-dumbbell, dumbbell, dumbbell-two-point and two-point.

We cannot decide upon the validity or invalidity of the Griesbach method for measurements of this sort. It might be of interest to note, however, that those experiments in which confirmatory results were obtained were largely of the class experiment type, and that when the investigations were carried into the laboratory, under much more rigidly controlled conditions, the confirmation was largely lacking.

It is interesting to note that the tactual sensitivity is practically the only modality upon which investigators have studied the effect of physical and mental work. Gineff (11) and Meumann (25) both suggested a number of years ago that if work had this effect upon tactual sensitivity, a similar effect should also be apparent for the other modalities.

Some few observations have been made for some of the other modalities, but one searches almost in vain throughout the literature for such studies. Vannod (34) and Binet (3) note a decrease in pain sensitivity as a result of mental work but they do not present their findings with any great degree of conviction. Baur (2) notes a decrease in auditory sensitivity on the basis of a most unsystematic investigation. Graziani (12, 13) finds that mental work has an effect upon both visual and auditory sensitivity. Recently several experiments have been performed with the aid of the Martin method of the measurement of induction shocks. Gruber (17) finds a decrease in the irritability of the dissected muscle as a result of muscular work, which may raise the threshold for contraction as much as 600 *per cent.* Finally Martin, Withington and Putnam (23) find a decrease in the sensitivity to faradic stimulation in human subjects from day to day throughout the week, with a return to the original high point after Sunday's interruption of the weekly routine. This they ascribe to fatigue.

In summary, then, we note that all of the measures of sensitivity which have been employed, were obtained for the stimulus threshold, that intensity of stimulus which could be just perceived. No investigations have been made on the effect of physical and mental work upon the difference thresholds, although these determinations can be made with much greater ease and precision than those for the stimulus thresholds. We also note that most of the investigations have been in the field of cutaneous sensitivity and here the results have been of an exceedingly divergent character. Very few experiments have been performed to ascertain the effect of mental or physical work upon sensory modalities other than the tactual.

2. Methods and Procedure

It, therefore, seemed of value to determine the effects of physical and mental work upon the difference thresholds for some sense modality other than the cutaneous. Experiments in lifted weights at once suggested themselves, inasmuch as with them there has been developed a technique which is extremely well understood and which leaves but little to be desired.

Our materials consisted of five pairs of small brass cylinders which were employed as stimuli. Each pair consisted of a standard stimulus of 100 grams and a comparison stimulus of 88, 92, 96, 100 or 104 grams. These stimuli were placed about the circumference of a table with a revolving top so that the stimuli could be brought successively directly under the hand of the subject. Thus the space errors were eliminated. The time errors were present in the first order, *i. e.*, the standard stimulus was always lifted first. The rate of lifting was regulated by the beats of a metronome so that the time error remained constant. Immediately after the lifting of each comparison weight a judgment was given verbally in terms of the second weight, the subject employing the three categories of 'lighter,' 'equal' and 'heavier,' which were defined in the usual manner. The observed relative frequencies of the different categories upon each of our comparison pairs thus obtained were treated in accordance with the methods of calculation developed by Urban.[1]

We employed five subjects throughout the investigation.[2] All of the subjects were advanced students in experimental psychology at Clark University. Several of these subjects had participated before in lifted weight experiments and were familiar with the particular technique which we employed. All of the subjects were given a preliminary series of 100 liftings of each of our comparison pairs before the beginning of the experiment. This was done so as to eliminate the early stages of progressive practice which Urban (33) and Fernberger (8) have shown to be of considerable effect. After this preliminary series our experiments were divided into two groups.

We first investigated the effect of mental work upon the

[1] For a more detailed description of the stimuli, the method of lifting and the treatment of results, *cf.* S. W. Fernberger, 'On the Relation of the Methods of Just Perceptible Differences and Constant Stimuli,' *Psychol. Monog.* XIV (Whole No. 61), 1913, 6–11; S. W. Fernberger, 'On the Elimination of the Two Extreme Intensities of the Comparison Stimuli in the Method of Constant Stimuli,' *Psychol. Rev.*, XXI., 1914, 337–340; F. M. Urban, 'Hilfstabellen für die Konstanzmethode,' *Arch. f. d. ges. Psychol.*, XXIV., 1912, 236–243.

[2] My thanks are due to the following, who kindly consented to act as subjects in this investigation: Miss E. Bowman and Messrs. H. R. Crosland, B. Hori, F. J. O'Brien and R. B. Teachout.

judgments to lifted weights. In this series, each daily session consisted of a test period before the mental work was performed, then a period of mental work which was followed by another test period. In the test period before the mental work we obtained, at each session, twenty judgments upon each of our five comparison pairs. These were broken up into two periods of ten judgments upon each pair with a rest period between these groups. The passing of 50 judgments without a rest seemed to be well within the fatigue and attention span of our subjects. Then came a period of one half hour's duration devoted to mental work. This mental work consisted in the reading of a passage of difficult German. The subjects were informed that they would have to report upon the section read and thus we had a check upon the fact that real, conscientious mental work was performed. After this period of one half hour's mental work, we had another test period of similar length to the one before the mental work was performed. Again we obtained 20 judgments upon each of our five comparison pairs with a rest period after the first group of ten judgments. During this rest period, the subjects were asked to report upon the material which they had read. Hence we believe that we obtained rest from the physical work of the actual lifting without any recovery from the effects of the mental work. We always employed a warming-up series before the judgments of each group of liftings were recorded. In this manner we obtained 300 judgments upon each of our five comparison pairs and from each of our five subjects for both of the test periods before and after the period of mental work. Our discussion of the effect of mental work is, therefore, based on a consideration of 15,000 individual judgments. The judgments for each subject were calculated in groups of 50 on each comparison pair, and hence each group of 50 contains the judgments from two and a half days' experimentation.

The criticism may be raised that one half hour's mental work is not a sufficiently extended period to show its effects upon the nervous system, which seems to be exceedingly resistant to effects of this sort. Unfortunately one is bound down, in such an investigation, to the single hour, as one

cannot obtain trained subjects for a longer period due to their other academic duties. And it may well be argued that the considerably longer periods employed by other investigators, particularly in the class experiments, are open to grave criticism. We cannot help but believe that class-room work from the early forenoon to the middle of the afternoon will involve a considerable amount of physical as well as mental work. We believe that if one is to test the effects of mental work and have that as pure as possible and with a minimum admixture of physical work, that one must employ relatively short periods with exceedingly intensive mental work. All of our subjects frequently volunteered the information that the period and the materials which we employed gave rise to fatigue sensations.

In our second group of experiments on the effects of physical work upon judgments for lifted weights, it was possible to control the work problem with much greater precision. The liftings were all made with the right hand and hence we believed that if the work would have any effect, it would be better to fatigue the particular group of muscles involved in the lifting. An adaptation of the Mosso ergograph proved to be exceptionally useful for our purpose, as with this we were able to fatigue the muscles of the right hand and forearm—those muscles particularly involved in the lifting. The physical work was carried on in every case to an extreme amount, indeed up to the point of painful fatigue. In the case of one subject, *B*, who had some trouble with the tendon of the second finger of the right hand, we had to abandon the ergograph as the means of obtaining the physical work and we substituted a hand dynamometer and found that continued contractions with this instrument suited our purpose very well.

In this portion of our experiment we had first, a test period before the physical work was performed and then a series of work and test periods following. In the test period before the physical work we obtained, at each session, 25 judgments on each comparison pair. These were divided into five groups of 5 judgments on each comparison pair with a rest period between. Thus by using exceedingly short test periods with

very frequent rests we were able to eliminate the factor of physical fatigue entirely in this part of the experiment. After the completion of this first test period, the subject was placed in the ergograph and did physical work until pain entered into the contractions and then he immediately started lifting in the second test series until we obtained five judgments upon each of our comparison pairs. The subject then performed physical work again and another short series of liftings was obtained. Five such alternating work and test periods completed the sitting. In every case, in both the test period before and after the physical work, the subjects were allowed a number of liftings for purposes of warming-up before the judgments were recorded. In this manner we obtained 300 judgments on each of our five comparison pairs and from every subject, for both the test series before and after the physical work. Our discussion of physical work is, therefore, based upon 15,000 individual judgments. For purposes of calculation, these judgments were divided into groups of 50 on each pair of weights, and hence each group of 50 contains the results of two days' experimentation. It may be of interest to note that all of our experiments, with the exception of those for subject *C*, were performed in the forenoon.

3. Results

(*a*) *The Effects of Mental Work*

We shall, of course, treat our results of the series of mental and physical work separately. Let us first consider the results of the effect of mental work on the judgments to lifted weights. The results of our calculations of the relative frequencies of the different categories of judgments, obtained and treated in accordance with the procedure of the method of constant stimuli, will be found in Tables I.–X. All of the tables show a similar arrangement. The first column contains the numbers of the series, *i. e.*, the groups of 50 judgments upon each comparison stimulus in the order in which they were taken. The second and third columns contain the values of h_1 and h_2, the coefficients of precision of the curves of the psychometric functions of the lighter and heavier judgments

TABLE I

SUBJECT *B*. BEFORE MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.09055	0.10886	94.26	96.68	2.42	95.47
2	0.11971	0.10184	95.89	98.45	2.56	97.17
3	0.08502	0.10363	93.94	98.36	4.42	96.15
4	0.12301	0.13520	94.05	95.92	1.87	94.98
5	0.11711	0.13464	95.86	96.99	1.13	96.42
6	0.12980	0.12406	96.45	98.03	1.58	97.24
Average...	0.11087	0.11804	95.08	97.40	2.33	96.24

TABLE II

SUBJECT *B*. AFTER MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.10424	0.10436	94.09	97.78	3.69	95.94
2	0.12446	0.12515	95.22	97.81	2.59	96.52
3	0.08028	0.08179	92.00	96.35	4.35	94.18
4	0.10542	0.10311	94.54	95.68	1.14	95.11
5	0.13895	0.14736	94.73	96.42	1.69	95.58
6	0.12116	0.13849	96.19	97.44	1.25	96.82
Average...	0.11242	0.11671	94.46	96.91	2.45	95.69

TABLE III

SUBJECT *C*. BEFORE MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.10299	0.09393	91.49	94.18	2.69	92.84
2	0.11878	0.10108	90.76	93.38	2.62	92.07
3	0.10476	0.07940	89.36	91.26	1.90	90.31
4	0.13669	0.11818	91.17	93.20	2.03	92.18
5	0.16710	0.13594	92.44	94.08	1.64	93.26
6	0.12146	0.11100	91.52	93.38	1.86	92.45
Average...	0.12530	0.10659	91.12	93.25	2.12	92.18

TABLE IV

SUBJECT *C*. AFTER MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.09954	0.08442	91.30	93.82	2.52	92.56
2	0.09921	0.11657	90.42	93.46	3.04	91.94
3	0.13530	0.11903	92.22	93.84	1.62	93.03
4	0.13208	0.12068	91.63	93.40	1.77	92.52
5	0.13379	0.11945	92.76	94.56	1.80	93.66
6	0.15220	0.13871	91.45	92.99	1.54	92.22
Average...	0.12535	0.11648	91.63	93.68	2.05	92.66

TABLE V

SUBJECT *H*. BEFORE MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.14350	0.13550	92.50	99.88	7.38	96.19
2	0.11102	0.09812	90.42	99.50	9.08	94.96
3	0.12468	0.09262	91.58	101.19	9.61	96.38
4	0.13390	0.11796	92.42	101.40	8.98	96.91
5	0.13708	0.11232	92.66	100.90	8.24	96.78
6	0.15555	0.12410	91.10	100.64	9.54	95.87
Average...	0.13429	0.11344	91.78	100.58	8.80	96.18

TABLE VI

SUBJECT *H*. AFTER MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.13170	0.12328	91.63	99.55	7.92	95.59
2	0.09925	0.11106	89.32	99.29	9.97	94.30
3	0.11804	0.08389	91.99	101.70	9.71	96.84
4	0.13244	0.12711	92.65	101.03	8.38	96.84
5	0.11716	0.11327	90.83	100.81	9.98	95.82
6	0.15146	0.13188	91.20	101.03	9.83	96.12
Average...	0.12501	0.11508	91.27	100.57	9.30	95.92

TABLE VII

SUBJECT *O*. BEFORE MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.11417	0.13127	96.44	98.52	2.08	97.48
2	0.15103	0.14150	96.03	98.26	2.23	97.14
3	0.11691	0.14226	95.55	99.18	3.63	97.36
4	0.12280	0.12378	94.96	98.39	3.43	96.68
5	0.11253	0.09650	94.83	98.93	4.10	96.88
6	0.15199	0.11070	93.90	96.42	2.52	95.16
Average...	0.12824	0.12434	95.28	98.28	3.00	96.78

TABLE VIII

SUBJECT *O*. AFTER MENTAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12811	0.11191	96.29	98.29	2.00	97.29
2	0.11300	0.12860	97.26	99.24	1.98	98.25
3	0.13500	0.11968	96.55	99.74	3.19	98.14
4	0.10271	0.11240	94.74	98.38	3.64	96.56
5	0.13033	0.12967	94.10	96.93	2.83	95.52
6	0.11534	0.12262	94.41	96.22	1.81	95.32
Average...	0.12075	0.12081	95.56	98.13	2.58	96.85

TABLE IX

SUBJECT *T.* BEFORE MENTAL WORK

Series	h_1	h_2	*D*	*I*	Interval of Uncertainty	Point of Subjective Equality
1	0.12385	0.09169	92.80	99.13	6.33	95.96
2	0.11902	0.09120	93.88	101.78	7.90	97.83
3	0.11656	0.12708	93.77	99.59	5.82	96.68
4	0.12498	0.16431	93.57	97.78	4.21	95.68
5	0.12784	0.14392	92.87	98.25	5.38	95.56
6	0.13974	0.12991	92.26	97.65	5.39	94.96
Average...	0.12533	0.12468	93.19	99.03	5.84	96.11

TABLE X

SUBJECT *T.* AFTER MENTAL WORK

Series	h_1	h_2	*D*	*I*	Interval of Uncertainty	Point of Subjective Equality
1	0.09755	0.10914	92.31	99.14	6.83	95.72
2	0.12610	0.15518	93.46	100.21	6.75	96.84
3	0.13511	0.13000	93.87	98.54	4.67	96.20
4	0.12684	0.14451	93.41	98.29	4.88	95.85
5	0.13512	0.15347	93.10	98.68	5.58	95.89
6	0.14904	0.13406	92.07	98.46	6.39	95.26
Average...	0.12829	0.13773	93.04	98.89	5.85	95.96

respectively. The next two columns, labeled *D* and *I*, give the values of the lower and upper thresholds respectively. The next columns give the values of the interval of uncertainty, *I–D*. It will be remembered that one half of this interval is the Threshold of Volkmann, which is recognized as the measure of the sensitivity of the subject. Finally, the last columns contain the values of the point of subjective equality. In each row will be found the values obtained from a treatment of the relative frequencies of the series indicated in the first column. The bottom row gives the average of the values for all of the series.

Two tables are given to the results of each subject. The tables with odd numbers (I., III., etc.) contain the constants of the psychometric functions and the values which follow from them for the series before mental work. The tables with the even numbers (II., IV., etc.) contain the similar values for the series after mental work.

The results for Subject *B* (Tables I. and II.) show that, on

the average for all of the results, there is exceedingly little change in the size of the values of the coefficients of precision for either the lighter or heavier judgments (h_1 and h_2). The coefficient of precision is, on the whole, slightly greater for the less judgments after mental work, but this holds true in only three of the six individual groups. On the other hand, the coefficient of precision of the heavier judgments is slightly smaller after mental work, but this again is true in only three cases of the six groups. Both thresholds (D and I) for this subject assume slightly lower values as a result of the mental work. For both the thresholds in the direction of decrease and increase this is true in five out of the six cases. But the two thresholds decrease in size as a result of the mental work to approximately equal amounts and hence the interval of uncertainty is practically the same for the average of all of the results. For the individual groups, the interval of uncertainty is larger in two cases, smaller in two cases and in two cases it remains practically the same. The point of subjective equality is, on the average, over one half a gram lower after mental work, but for the individual groups, this value is lower in only four cases and higher in two.

The results for Subject *C* (Tables III. and IV.) show tendencies as a result of mental work that are somewhat comparable to those of Subject *B*, just considered. The average of the coefficients of precision for the lighter judgments is almost identical in the results before and after mental work. In the individual groups, this value is higher three times and lower three times after the mental work, as compared with the corresponding values before the work was performed. On the average, the coefficient of precision for the heavier judgments is greater after the mental work but this is true for only four of the six individual groups. Both of the thresholds in the directions of decrease and increase are higher after mental work than before the work was performed. But this relation is by no means constant. For the threshold in the direction of decrease, the values for the individual groups are larger in three cases and smaller in three after the mental work; while for the threshold in the direction of increase, the values

after the mental work are higher in four groups out of the six. The values of the interval of uncertainty before and after the work for this subject, are almost identical, the value after the work being, on the average, only 0.07 gram less than the corresponding value before, the values for the individual groups being smaller four times and larger twice after the mental work. The point of subjective equality is nearly half a gram larger after mental work than before, on the average, but three of the individual groups show values that are smaller than the corresponding values before mental work.

Subject *H* (Tables V. and VI.) shows values, as a result of the mental work, which are very different from those of the two subjects which we have discussed just above. For this subject, the coefficient of precision of the lighter judgments is less on the average after the mental work, and, indeed, the values are less in every one of the six individual groups. The average coefficient of precision for the heavier judgments is slightly greater after the mental work, but is greater in only three of the six individual groups. The threshold in the direction of decrease is lower, on the average, after the mental work by a little over half a gram, but again is less in only three of the six individual groups. The average values of the threshold in the direction of increase are almost identical, being less in three cases, larger in two and almost equal in one of the individual groups. Inasmuch as the average upper threshold remains constant while the lower threshold assumes a lower value, the size of the interval of uncertainty after the mental work is greater than before the work was performed, by exactly half a gram. The individual values of the interval of uncertainty are greater after mental work in five out of six cases. The average point of subjective equality is slightly lower after mental work, being lower in four of the six groups.

The results of Subject *O* (Tables VII. and VIII.) are again different from those of any of the three subjects already discussed. For this subject, the average values of the coefficients of precision for both the lighter and heavier judgments assume lower values after the mental work, considerably lower in the case of the coefficient of precision for the lighter judgments.

However, the values for the individual groups in this case are lower in only three of the six cases, while for the coefficient for the heavier judgments, the values are lower in four of the six cases after mental work. The average value of the lower threshold after mental work is slightly higher than its corresponding value, but is higher in only three of the six individual groups. The upper threshold, on the other hand, after mental work assumes a slightly lower value than its corresponding quantity, but is lower in only three cases, higher in two, with one case almost identical for the individual groups. Hence the average value of the interval of uncertainty for this subject is over four tenths of a gram less after the mental work, and is less in five of the six groups. The average values of the point of subjective equality are almost identical; being 0.06 gram higher after mental work, but being higher in only three of the six groups.

Subject *T* (Tables IX. and X.) shows values which again are different from the others. For this subject, the average values of the coefficients of precision for both the lighter and heavier judgments are larger after the mental work; very considerably larger in the case for the coefficient for the heavier judgments. For the individual groups, the coefficient of precision for the lighter judgments is larger, after mental work, in five cases out of six; while that for the heavier judgments is larger, after mental work, in five cases out of six. Both thresholds assume, on the average, slightly lower values after the mental work; that in the direction of decrease being lower in four cases out of six; that in the direction of increase being lower in only two cases out of six. The average values of the interval of uncertainty before and after mental work are almost identical; the size of the interval after the work being only 0.01 gram larger, but being larger in four of the six individual groups. The average value of the point of subjective equality after the mental work is slightly lower than the corresponding value before the work was performed, but it is lower in only three of the individual groups.

One is impressed, we believe, by the extreme variability of the apparent effect of mental work as shown by the comparison

of the values of the different groups of 50 judgments on each comparison pair for the same subjects. In the case of very few values are any general tendencies of increase or decrease apparent for any subject. In only one case (Subject *H*, h_1) are all of the values after mental work either greater or less than those before the work was performed in all of the six individual groups. In only five cases are there tendencies strong enough to show a regular increase or decrease in five of the six groups. These are: Subject *B*, the two thresholds decrease after mental work; Subject *H*, the interval of uncertainty is greater, and in Subject *O*, it is less after mental work; and in the case of Subject *T*, the coefficient of precision for the lighter judgments is less. In all of the other averages for the values for each subject, the quantities contain at least two individual group readings which are in opposition to the average.

We find not only this great variability of the apparent effect of mental work upon the values for each individual subject, but also when we compare the average values for all of the subjects. These average values are given in Tables XI. and XII. These tables show the same arrangements as the others,

TABLE XI

AVERAGE OF ALL SUBJECTS. BEFORE MENTAL WORK

Subjects	h_1	h_2	*D*	*I*	Interval of Uncertainty	Point of Subjective Equality
B	0.11087	0.11804	95.08	97.40	2.33	96.24
C	0.12530	0.10659	91.12	93.25	2.12	92.18
H	0.13429	0.11344	91.78	100.58	8.80	96.18
O	0.12824	0.12434	95.28	98.28	3.00	96.78
T	0.12533	0.12468	93.19	99.03	5.84	96.11
Average...	0.12481	0.11742	93.29	97.71	4.42	95.50

TABLE XII

AVERAGE OF ALL SUBJECTS. AFTER MENTAL WORK

Subjects	h_1	h_2	*D*	*I*	Interval of Uncertainty	Point of Subjective Equality
B	0.11242	0.11671	94.46	96.91	2.45	95.69
C	0.12535	0.11648	91.63	93.68	2.05	92.66
H	0.12501	0.11508	91.27	100.57	9.30	95.92
O	0.12075	0.12081	95.56	98.13	2.58	96.85
T	0.12829	0.13773	93.04	98.89	5.85	95.96
Average...	0.12236	0.12136	93.19	97.64	4.45	95.42

except that the values in each row are the average values for each subject, whose initial is found in the first column. The bottom row contains the averages of these, or the average of all of the judgments obtained from this part of the experiment. Table XI. contains the values obtained before and Table XII. those obtained after the mental work.

An examination of these tables reveals the fact that the coefficient of precision for the lighter judgments assumes a larger value, after the mental work, for two subjects, smaller for two and in one case the values are almost identical. The average for all of the subjects gives values which are very similar, but which are slightly smaller after the mental work. In the case of the coefficient of precision for the heavier judgments, the values after mental work are larger in the case of three subjects and smaller in the case of the other two; on the average this value is somewhat larger after the work for the entire series of experiments. The threshold in the direction of decrease is slightly smaller after the mental work but only to the extent of 0.10 gram. Three subjects give results which conform to this average while two do not. The threshold in the direction of increase is again slightly smaller, on the average, after mental work; the difference being only 0.07 gram. One subject gives results which do not conform, three show such little variation that the values may be considered identical while the results of the fifth subject conform to the average. The average values for all of the subjects for the interval of uncertainty before and after mental work are almost astoundingly similar; the interval after mental work being only 0.03 gram larger than the corresponding value. Two subjects conform to this average, two subjects do not and one gives practically identical values. The total average of the point of subjective equality after mental work is slightly lower than the corresponding value before work, the difference being only 0.08 gram. Three subjects conform to this average and two do not.

We have pointed out the extreme variability in the results for each individual in the apparent effects of mental work upon the judgments to lifted weights, and we have also pointed out

a similar extreme variability in the comparison of the results of the different subjects. We also wish to emphasize the extremely great similarity of the average results for all of the subjects. This coincidence of the total average results for the values before and after mental work is particularly marked when we consider both the upper and lower thesholds, the interval of uncertainty and the point of subjective equality. Great variability has always been found in lifted weight experiments and we believe that the divergence of the results for each subject may be explained in terms of chance variations. When we consider the final averages, we must conclude that intensive mental work, for a short period, but work which was intensive and prolonged enough to produce fatigue sensations, has no apparent effect upon the judgments in lifted weight experiments.

(*b*) *The Effects of Physical Work*

Let us now turn to a discussion of our results on the effects of physical work on the judgments to lifted weights. These

TABLE XIII

SUBJECT *B*. BEFORE PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.13636	0.14526	97.27	97.94	0.67	97.60
2	0.13418	0.14172	96.62	98.29	1.67	97.46
3	0.11666	0.14800	96.30	99.23	2.93	97.76
4	0.13227	0.12778	97.37	98.85	1.48	98.11
5	0.10690	0.11453	96.83	97.89	1.06	97.36
6	0.12142	0.11756	98.24	98.71	0.47	98.48
Average...	0.12463	0.13248	97.10	98.48	1.38	97.80

TABLE XIV

SUBJECT *B*. AFTER PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12054	0.12131	94.09	95.39	1.30	94.74
2	0.13296	0.12288	93.16	95.78	2.62	94.47
3	0.09924	0.11286	90.94	95.77	4.83	93.36
4	0.11694	0.12350	92.93	95.31	2.38	94.12
5	0.13052	0.12771	92.81	94.64	1.83	93.72
6	0.11168	0.11550	94.11	95.30	1.19	94.70
Average...	0.11865	0.12063	93.01	95.36	2.36	94.18

TABLE XV

SUBJECT *C.* BEFORE PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12348	0.11851	91.85	93.58	1.73	92.72
2	0.11800	0.12964	91.17	92.90	1.73	92.04
3	0.13254	0.11846	92.22	93.99	1.77	93.10
4	0.15145	0.14368	92.27	95.27	3.00	93.77
5	0.14538	0.14870	94.51	96.89	2.38	95.70
6	0.14349	0.13071	94.70	96.90	2.20	95.80
Average...	0.13573	0.13162	92.79	94.92	2.14	93.86

TABLE XVI

SUBJECT *C.* AFTER PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12705	0.09996	89.57	91.18	1.61	90.38
2	0.13432	0.10337	88.52	90.49	1.97	89.50
3	0.12487	0.10422	88.75	91.65	2.90	90.20
4	0.13480	0.11038	89.55	93.39	3.84	91.47
5	0.12012	0.12333	90.65	93.86	3.21	92.26
6	0.12802	0.10395	90.72	93.82	3.10	92.27
Average...	0.12820	0.10754	89.63	92.40	2.77	91.01

TABLE XVII

SUBJECT *H.* BEFORE PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12380	0.14242	92.84	99.80	6.96	96.32
2	0.09811	0.11658	91.45	99.90	8.45	95.68
3	0.09594	0.12205	92.97	100.93	7.96	96.95
4	0.11776	0.13025	94.13	101.73	7.60	97.93
5	0.13010	0.14963	94.26	100.30	6.04	97.28
6	0.13092	0.13979	94.57	100.48	5.91	97.52
Average...	0.11610	0.13345	93.37	100.52	7.15	96.95

TABLE XVIII

SUBJECT *H.* AFTER PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.15748	0.13562	90.04	98.21	8.17	94.12
2	0.13603	0.12253	89.41	98.58	9.17	94.00
3	0.12114	0.09264	89.82	98.88	9.06	94.35
4	0.11706	0.10188	90.36	99.52	9.16	94.94
5	0.13048	0.11251	91.34	99.04	7.70	95.19
6	0.14048	0.11513	90.74	98.42	7.68	94.58
Average...	0.13378	0.11338	90.28	98.78	8.49	94.53

TABLE XIX

SUBJECT *O.* BEFORE PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.11384	0.13896	94.91	96.83	1.92	95.87
2	0.12345	0.14300	95.69	98.39	2.70	97.04
3	0.14334	0.14892	97.36	99.06	1.70	98.21
4	0.10154	0.12504	98.10	100.29	2.19	99.20
5	0.12512	0.12482	95.75	98.07	2.32	96.91
6	0.13998	0.14207	96.93	98.71	1.78	97.82
Average...	0.12454	0.13714	96.46	98.56	2.10	97.51

TABLE XX

SUBJECT *O.* AFTER PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12629	0.12700	94.32	95.51	1.19	94.92
2	0.11889	0.14745	93.96	97.22	3.26	95.59
3	0.14872	0.15246	95.34	97.22	1.88	96.28
4	0.14464	0.12841	96.08	98.62	2.54	97.35
5	0.12183	0.12834	93.36	96.31	2.95	94.84
6	0.12630	0.13734	93.98	96.44	2.46	95.21
Average...	0.13111	0.13683	94.51	96.89	2.38	95.70

TABLE XXI

SUBJECT *T.* BEFORE PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.14418	0.13678	94.92	98.52	3.60	96.72
2	0.13720	0.15238	95.97	98.89	2.92	97.43
3	0.11700	0.14766	95.60	98.98	3.38	97.29
4	0.11454	0.12721	95.11	98.96	3.85	97.04
5	0.11680	0.13795	95.89	98.89	3.00	97.39
6	0.11808	0.12788	94.98	99.14	4.16	97.06
Average...	0.12463	0.13831	95.41	98.90	3.48	97.16

TABLE XXII

SUBJECT *T.* AFTER PHYSICAL WORK

Series	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
1	0.12796	0.13186	91.64	97.02	5.38	94.33
2	0.15804	0.13962	92.00	96.71	4.71	94.36
3	0.13068	0.13192	91.55	96.38	4.83	93.96
4	0.12498	0.12212	91.96	97.03	5.07	94.50
5	0.11493	0.12847	91.79	96.97	5.18	94.38
6	0.10940	0.11967	90.89	96.57	5.68	93.73
Average...	0.12766	0.12894	91.64	96.78	5.14	94.21

results are given in Tables XIII.–XXII. These tables have a similar arrangement to Tables I.–X. Two tables are again given to a presentation of the results of each subject, tables with the odd numbers (XIII., XV., etc.) containing the results for the series before physical work, and the tables with the even numbers (XIV., XVI., etc.) containing the results for the series after physical work.

An examination of these tables shows that physical work has the same general effect upon the values of the thresholds, the interval of uncertainty and the point of subjective equality for all of our subjects. The tendency in all of these cases is always in the same direction,—the variations being only in degree. Hence we will treat these values later as a group.

Let us first turn our attention to a consideration of the coefficients of precision of the lighter judgments. For Subject *B* the average value is less after the physical work than before it; this is true in five cases out of the six individual groups. The same tendency is true for Subject *C* with four of the six groups confirming the average. The other three subjects, however, give opposite results, as the coefficient of precision of the lighter judgments is larger on the average after physical work than before it. In the case of Subject *H* five of the six groups confirm the average; for Subjects *O* and *T* three of the six groups.

For all of our subjects the value of the coefficient of precision of the heavier judgments is smaller after the physical work on the average. For Subject *B*, this average is considerably smaller, five of the six groups confirming the average. In the case of Subject *C*, the average coefficient is very much smaller after the physical work and all of the individual groups show the same tendency. Five of the six groups of Subject *H* agree with the average which is considerably smaller after physical work. For Subject *O*, the coefficient of precision of the heavier judgments after physical work is slightly smaller, but there is only an inconsiderable difference, only two groups agreeing with the average. The values after physical work for Subject *T* are somewhat lower with all six groups showing a tendency in the same direction as the average.

The effects of physical work become very apparent upon the values of the thresholds in the direction of decrease. In the case of every individual group and for every subject, the lower threshold after physical work assumes a lower value than the corresponding quantity before the work was performed. The amount of decrease is by no means constant for the different groups and varies to a certain extent for the different subjects. The average differences in the different cases are: for Subject *B*—4.09 grams; for Subject *C*—3.16 grams; for Subject *H*—3.09 grams; for Subject *O*—1.95 grams and for Subject *T*—3.77 grams.

The effects of physical work upon the upper thresholds are in the same direction and equally as apparent. The thresholds in the direction of increase are smaller after physical work than before it and this relation holds true for every individual series for every subject. The degree of this effect upon the threshold varies not only for the same subject from series to series, but also for the different subjects. The average differences in these cases are: for Subject *B*—3.12 grams; for Subject *C*—2.52 grams; for Subject *H*—1.74 grams; for Subject *O*—1.67 grams and for Subject *T*—2.12 grams.

Inasmuch as the differences between the sizes of the lower threshold before and after physical work is greater than those of the upper threshold, there is a tendency for the two thresholds to draw further apart and hence to increase the size of the interval of uncertainty. This interval is greater on the average, after physical work for every subject and, indeed, for every individual group with the exception of two (Subject *C*, Series 1 and Subject *O*, Series 1). The amount of difference again varies for different groups for the same subjects and for the different subjects. The average amount of increase of the size of the interval of uncertainty for the different subjects is: for Subject *B*—0.98 gram; for Subject *C*—0.63 gram; for Subject *H*—1.34 grams; for Subject *O*—0.28 gram and for Subject *T*—1.66 grams.

Inasmuch as both the thresholds in the directions of decrease and increase assume lower values after physical work, there is a marked lowering of the point of subjective equality. This

decrease in size of the point of subjective equality, as a result of physical work, is true invariably for every group of every subject. Again there is considerable variation as to the extent of this effect of physical work both for the same subject at different times and when we compare the averages for the different subjects. The average decrease of the size of the point of subjective equality for the different subjects is: for Subject *B*—3.62 grams; for Subject *C*—2.85 grams; for Subject *H*—2.42 grams; for Subject *O*—1.81 grams and for Subject *T*—2.95 grams.

For convenience we have brought together the averages of all of our five subjects into Tables XXIII. and XXIV. The

TABLE XXIII

AVERAGE OF ALL SUBJECTS. BEFORE PHYSICAL WORK

Subjects	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
B	0.12463	0.13248	97.10	98.48	1.38	97.80
C	0.13573	0.13162	92.79	94.92	2.14	93.86
H	0.11610	0.13345	93.37	100.52	7.15	96.95
O	0.12454	0.13714	96.46	98.56	2.10	97.51
T	0.12463	0.13831	95.41	98.90	3.48	97.16
Average...	0.12513	0.13460	95.03	98.28	3.25	96.66

TABLE XXIV

AVERAGE OF ALL SUBJECTS. AFTER PHYSICAL WORK

Subjects	h_1	h_2	D	I	Interval of Uncertainty	Point of Subjective Equality
B	0.11865	0.12063	93.01	95.36	2.36	94.18
C	0.12820	0.10754	89.63	92.40	2.77	91.01
H	0.13378	0.11338	90.28	98.78	8.49	94.53
O	0.13111	0.13683	94.51	96.89	2.38	95.70
T	0.12766	0.12894	91.64	96.78	5.14	94.21
Average...	0.12788	0.12146	91.81	96.04	4.23	93.93

first of these tables contains the values for the lifted weight series before physical work, and the latter table the values for these after the work was completed. These tables are similarly constructed to the others in this paper. Each row contains the values for the subject whose initial appears in the first column. The bottom row contains the averages for all of our results in this portion of our experiment.

The average for all of the subjects shows that the value of the coefficient of precision for the lighter judgments after physical work is slightly larger than the corresponding value for the series before the work was performed. The averages of three subjects agree with this general average, while two subjects fail to confirm it. The total average of the coefficient of precision of the heavier judgments is considerably less after the physical work and the averages of all of the subjects are in agreement with this. In the case of all of our subjects, the thresholds in both the directions of decrease and increase are considerably smaller after the physical work. The total average difference is, in the case of the lower threshold, 3.22 grams; and, in the case of the upper threshold, 2.24 grams. The interval of uncertainty is considerably larger after physical work and this is found to be true for all of our subjects. This interval is 0.98 gram larger after physical work for the total average. All of the subjects also show a marked decrease in the size of the magnitude of the point of subjective equality after physical work; the difference in the total average for all of our subjects being 2.73 grams.

The extremely great increase in the size of the interval of uncertainty (0.98 gram for the total average) is of exceedingly great importance. It is one half of this interval which is the recognized measure of sensitivity and hence we must conclude that, for our experiments, the average sensitivity of all of our subjects was lowered over 30 *per cent.* as a result of the physical work. This is an exceedingly large increase and would have a great influence in any experiments in lifted weights in which the fatigue element should enter. We wish to note, however, that our physical fatigue was extreme, inasmuch as we worked the particular set of muscles involved in the lifting up to the point where pain entered into the work. It is of interest to note that physical work impairs the real efficiency of the sensitivity directly and not as a distraction. Mitchell (26) found that distractions in lifted weight experiments decreased the size of the interval of uncertainty, while we obtained the exactly opposite result, inasmuch as we found that physical work increased the size of this interval, which of course represents a lowered sensitivity.

The amount of decrease in the size of the point of subjective equality is another very evident effect of physical work in lifted weight experiments. This fact means that, after the physical work, the time error was more effective and hence led to a greater overestimation of the second weight than had been the case before the physical work had been performed. This was, perhaps, due to the fact that the physical work seemed to have considerable effect upon the absolute impressions of the weights themselves. Our subjects frequently volunteered the information that, after the work periods, the weights seemed absolutely very light.

4. Summary and Conclusions

The above results and discussion may be summarized as follows:

1. Intensive mental work, for the period of a half hour, does not seem to have any influence on the formation of judgments in lifted weight experiments, although this work was extensive and intensive enough to arouse fatigue sensations. On the average of a large number of liftings from each of five subjects, the values of the interval of uncertainty (twice the measure of sensitivity) and of the point of subjective equality are found to be almost identical for the groups of liftings before and after the mental work was performed. Certain tendencies of increase and decrease in these values, in the magnitudes of the thresholds and in the coefficients of precision of the lighter and heavier judgments are to be found in the averages of some of our subjects. These tendencies, however, are so variable, when we compare the results of the different subjects, and indeed, in most cases, when we compare the different groups of reactions of the same subject, that we must conclude that they are due to chance influences and not to the mental work.

2. Very intensive physical work of the muscles utilized in the liftings, on the other hand, has a marked and exceedingly great influence on the formation of judgments in lifted weight experiments. Physical work has little or, at least, a variable effect on the coefficient of precision for the lighter judgments. Physical work has a tendency, strongly marked and invariably

present, to decrease the size of the coefficient of precision of the heavier judgments. Physical work tends to decrease, strongly and invariably, the size of both the lower and upper thresholds, the decrease being much more marked on the lower than the upper threshold. Also the size of the interval of uncertainty is markedly increased by physical work, by nearly a gram for the total average of all of our experiments. This is a very marked decrease in the sensitivity of over 30 *per cent.*, which must be considered in lifted weight experiments. Physical work has also a marked and invariable effect of decreasing the size of the point of subjective equality or, in other words, there is a greater tendency to overestimate the second weight of each comparison pair after physical work.

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THE TRABUE COMPLETION TEST AS APPLIED TO DELINQUENT GIRLS[1]

BY ALIDA C. BOWLER

The purpose of this study was two-fold:

1. To determine whether an individual's graded completion test achievement might be considered indicative, to some extent, of his general mental ability.

2. To obtain a practical, graded series short enough to be completed in fifteen or twenty minutes.

The material used consisted of the original 56 mutilated sentences presented by Prof. M. R. Trabue at the meeting of this section December 31, 1914. These were printed on one sheet of paper, folded to form four pages. Sentences 1–20 were on the first page, 21–36 on the second, 37–47 on the third, and 48–56 on the fourth.

The subjects were called in to an ordinary school room in small groups of from 3–5. Although on each page was a printed line of instruction which read "On each line of dots write the word which makes the best meaning," they were always given a simple oral explanation before they received the sheets. They were told something like this: "There is a sheet on which you will find some sentences. Something has been left out of each sentence. I want you to read each one, think about it, and then write in the word which seems to you to make the best sense. Wherever there is a blank you must write a word. Just one word in each blank." They were then given the sheets with page one folded out, and having completed that the sheet was turned and they were told to do the same with the next page, and so on. In almost every case they were allowed to work as long as they wished. Occasionally a word of encouragement was spoken.

[1] Contributed from the Bureau of Juvenile Research, Columbus, Ohio. Read before Section L of the American Association for the Advancement of Science at Columbus, Dec. 29, 1915.

In some cases of low mentality they were not urged to keep at work when they seemed to have reached their limit and wished to "give up." Thus a certain amount of error may have crept in. That is, a girl of that type might possibly have filled a single blank correctly here and there and thus raised her total score slightly.

The test was given through the kind coöperation of Mrs. Margaret McNamara, chief matron, to some 256 delinquent girls at the Ohio State Girls' Industrial School. They range in actual chronological age from 13 to 18 years. Each had previously been given a rating by the Yerkes-Bridges Point Scale. These ratings range from 40–97 points.

In scoring results each blank correctly filled was given one point credit. Since it was our desire to test the ability to complete an idea logically, rather than the ability to use language correctly, it soon became evident that a system of half-credits was desirable. For, with this type of girl, inelegant diction and grammatical errors are more the rule than the exception. It was quite common to find "The kind lady *give* the poor man a dollar," "The *girls* plays with her doll all day," etc. Blanks calling for prepositions were very likely to be filled awkwardly. They made little discrimination between adjective and adverb, frequently writing, "The stars *are* brightly at night," and "The poor baby cries as if it were *bad* sick." Each blank which was so filled as to develop the idea logically, even though awkwardly, was given half-credit. Each girl was then given: (1) a score on her performance by sentence groups or pages, and (2) a score which represented the total number of blanks correctly filled.

For purposes of convenience in studying results, the subjects were divided by means of their point-scale ratings into six groups. Group *A* consists of 12 girls scoring 90–97 inclusive, group *B*, 62 girls scoring 80–89, *C*, 64 girls scoring 70–79, *D*, 70 girls scoring 60–69, *E*, 37 girls scoring 50–59, and *F*, 11 girls scoring 40–49. The curves in Fig. 1 show the average percentage achievements of each group for the four pages of the test, (*a*) being the curve for page 1, sentences

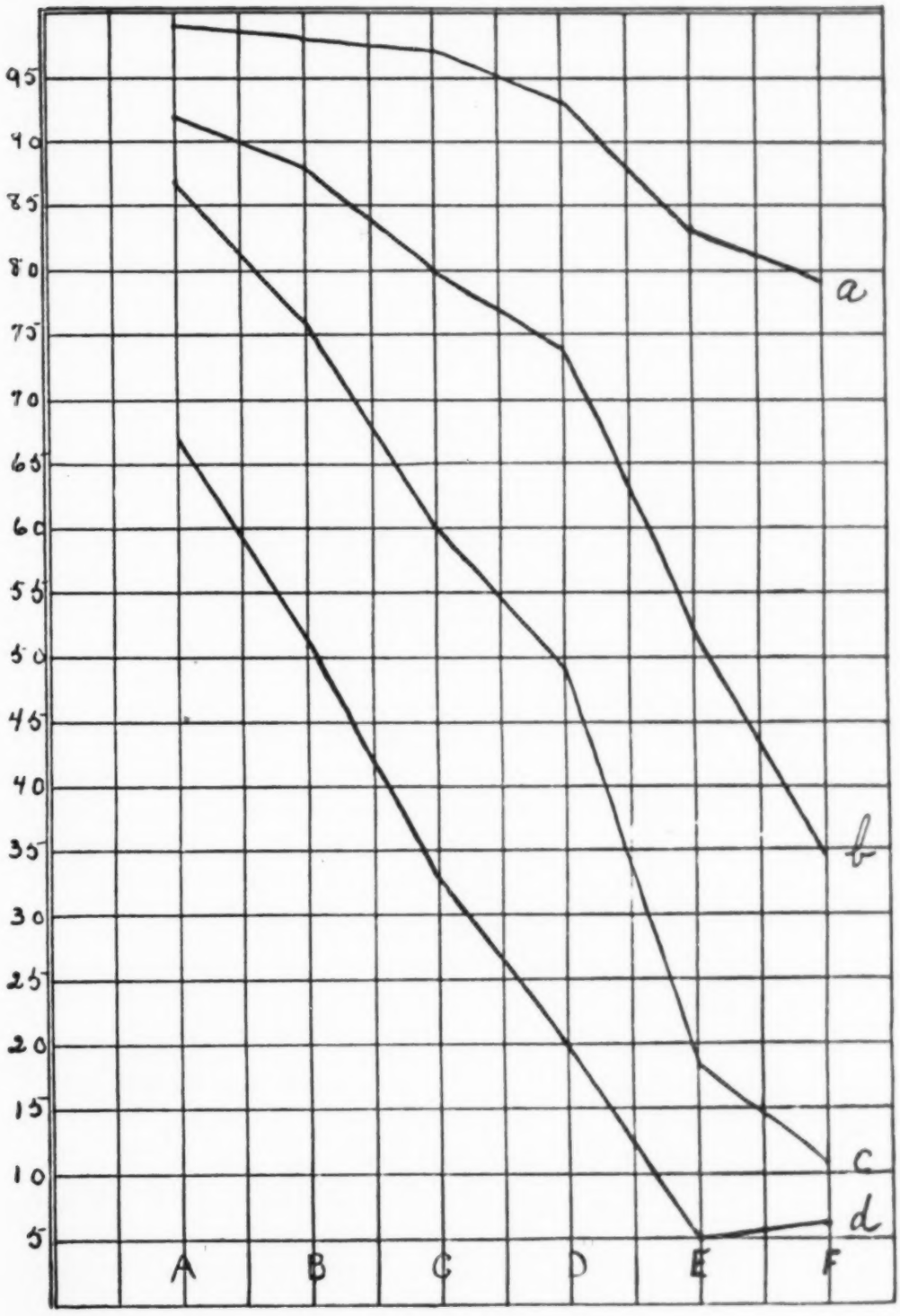

FIG. 1. *a* = aver. per cent. scores on sentences 1–20; *b* = aver. per cent. scores on sentences 21–36; *c* = aver. per cent. scores on sentences 37–47; *d* = aver. per cent. scores on sentences 48–56.

1–20, (*b*) for page 2, sentences 21–36, (*c*) page 3, sentences 37–47, and (*d*) page 4, sentences 48–56. These curves show that there is a decrease in ability from group to group in each case, except 1 *d*, groups *E* to *F*, and it should be observed that *F* is a very small group. It is evident that sentences 1–20 are too easy to detect any great differences for girls who can make sixty or more points by the Yerkes-Bridges Scale. The same may be said for sentences 21–36. From this point on, however, there is a decided drop from group to group. Fig. 1 also shows that the test is essentially a graded one. Within each group there is a decrease in achievement for each succeeding page of the test. Nowhere do the curves cross.

From this glimpse of the results in fragments it is easy to pass to Fig. 2, in which curve (*a*) represents the average percentage achievement for the six groups for the entire 56 sentences. The decrease in ability is quite regular and corresponds rather strikingly to the average point scale scores for the six groups as represented by curve (*c*). This close correspondence suggested the working out of the correlation between the two. By the Pearson "product-moments" method this coefficient of correlation, between the Yerkes-Bridges Point Scale scores and percentage achievements of individuals in the Completion Tests, proved to be .79, with a P.E. of .0157. It therefore seems reasonable to conclude that an individual's grade completion test achievement is, to some extent, indicative of his general mental ability.

The time spent upon the test varied from twenty minutes to one hour. In order to cut down the series to one which could be completed in fifteen or twenty minutes, a careful study of the value of the sentences was made. The percentage of the entire 256 correctly completing each sentence was determined. An arrangement in order of difficulty based upon this computation proved somewhat different from that derived by Professor Trabue from New York school children. Sentence 4, correctly completed by 98 per cent., became first while 54, correctly completed by but 4 per cent., became last. A shorter series was then made up,

eliminating, so far as possible, those sentences in which half-errors were constantly made. The choice fell upon sentences 4, 19, 3, 6, 5, 14, 22, 26, 29, 18, 30, 28, 35, 39, 36, 45, 47, 50, 32, 52, arranged in that order by reason of the

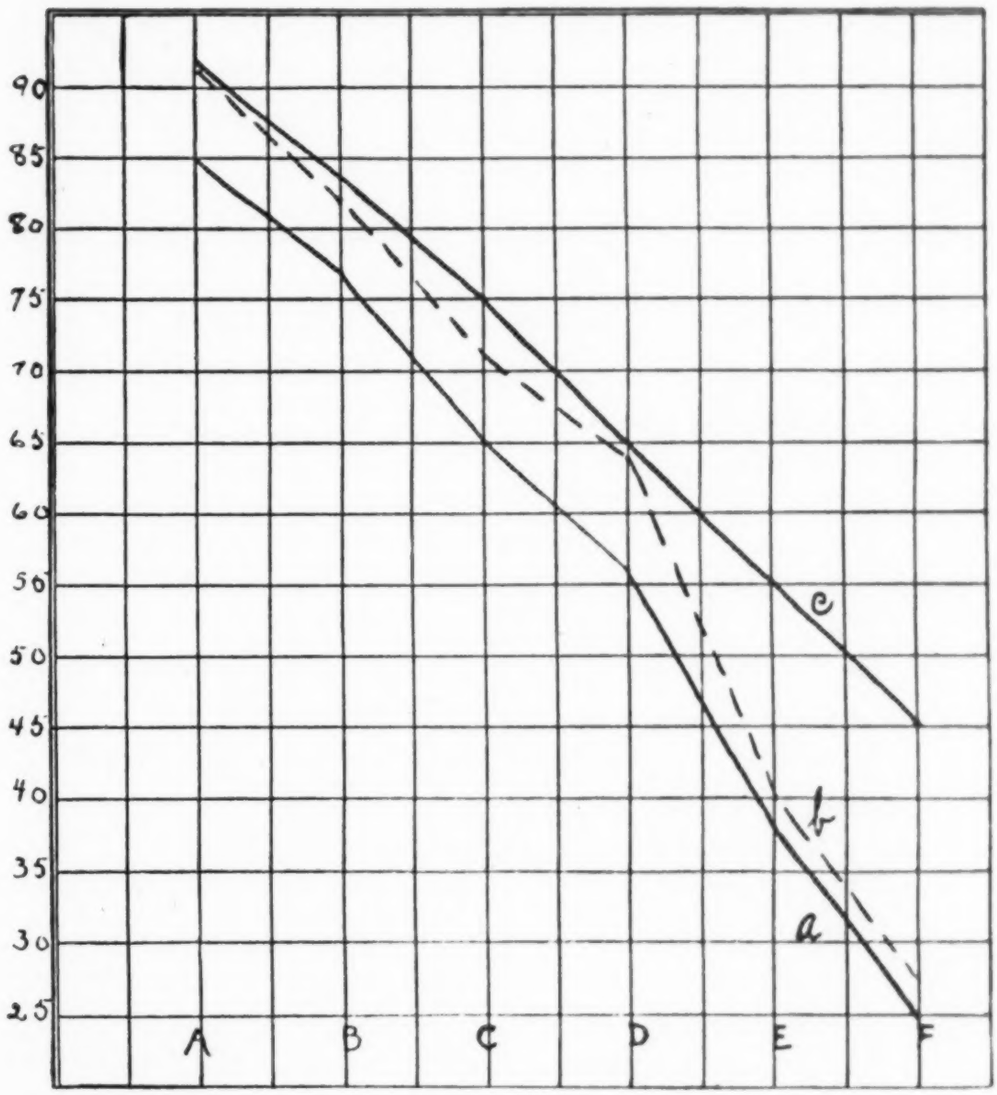

FIG. 2. *a* = aver. per cent. scores on entire test; *b* = aver. per cent. scores on 20 suggested sentences; *c* = aver. Yerkes-Bridges Point Scale Scores.

percentage of our subjects correctly completing each. These make up a suggested series of 20 sentences, with a total of 50 blanks, increasing gradually in difficulty from sentence 1, correctly completed by 98 per cent., to sentence 20 correctly completed by but 9 per cent. Curve (*b*) in Fig. 11 represents

the average achievement of each group of subjects on these 20 sentences. It so nearly parallels curve (*a*), which represents the entire series of 56, as to seem to be quite as effective a test. Moreover it seems doubly practical, since it is graded and is short enough to be completed in fifteen or twenty minutes. It is also easily scored, on a percentage basis, if each of its fifty blanks be given 2 points credit for correct filling, and 1 point for logical, but awkward, completion.

SHORT COMPLETION TEST OF TWENTY SENTENCES, AND FIFTY BLANKS

256 Scores Summarized in Curve (b) of Fig. 2

1. We are going.....school.
2. The girl fell and.....her head.
3. I see.....man and the boy.
4. The.....is barking at the car.
5. Men.....older than boys.
6. When the.....grows older he.....be a man.
7. Time.....often more valuable.....money.
8. Boys who play..... .....mud get their hands .....
9. Boys and.....soon become.....and women.
10. The best.....to sleep is at night.
11. The boy who.....hard.....do well.
12. The poor little.....has.....nothing to.....; he is hungry.
13. Brothers and sisters.....always.....to help .....other and should.....quarrel.
14. If a person injures one by....., without having intended any....., one should..... .....insulted.
15. Worry.....never improved a situation but has .....made conditions.....
16. To.....many things.....ever finishing any of them.....a.....habit.
17. Children should.....that after all nobody is .....to care much more.....their success than..... .....parents.

18. When two persons.....about.....which neither understands they.....almost.....to disagree.

19. One's.....do.....always express his thoughts.

20. When one feels drowsy and....., it.....happens that he is.....to fix his attention very successfully..... anything.

THE EFFECT ON FOVEAL VISION OF BRIGHT SURROUNDINGS—IV

BY PERCY W. COBB

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The problem dealt with in the present paper is essentially the same as one previously treated under similar title. (1). The present work is however limited to the investigation of difference-threshold under various conditions as to brightness of field and surroundings. The modification of the apparatus from the form in which it was formerly used has been made the subject of a separate communication. (2).

The observations were taken under fourteen different sets of conditions as indicated in the tables of results. These sets naturally divide themselves into two groups, the set designated *o* being common to the two. In this case the field and its surroundings are of equal brightness, and the two groups are completed, the one (*a* to *g*) by keeping the surroundings at the same brightness as in the case of *o* and using various brightnesses of field, and the other (*u* to *z*) similarly by keeping the field constant and varying the brightness of the surroundings.

Procedure

The observations were taken in groups of 100, which consisted of 25 different stimuli each presented 4 times, the entire group of 100 being given in shuffled order with a short rest after each 25 exposures. Such a group of experiments occupied about one half hour. Five such groups constituted the work for each observer under each set of conditions; in all 500 experiments, 20 on each stimulus.

The 25 different stimuli consisted of 1 in which no difference existed between the two halves of the field, and 12 each with the difference on the right and left halves, these differ-

ences increasing by uniform steps from 1 to 12 units. As it developed in the course of the work that as a rule a certain practice effect was taking place these units had to be changed from time to time.

The observer, after three seconds' observation of the test-stimulus, rendered one of three judgments: either that the right or the left half of the field appeared the brighter, or that neither of these two judgments could be rendered. The judgment was therefore as to the direction of the difference.

The 5 successive experimental sessions under each of the 14 sets of conditions were so distributed over the entire time of the whole 70 that each was represented as fairly as possible at all parts of the period.

Method of Computation

It was at first intended to compute the results by the method of constant stimuli but, as stated, the stimuli had to be changed during the course of the work. Even where this was not the case the number of experiments on each stimulus, to have been sufficient to obliterate all inversions of the first order, would have been prohibitively large considering the large number of sets of experimental conditions

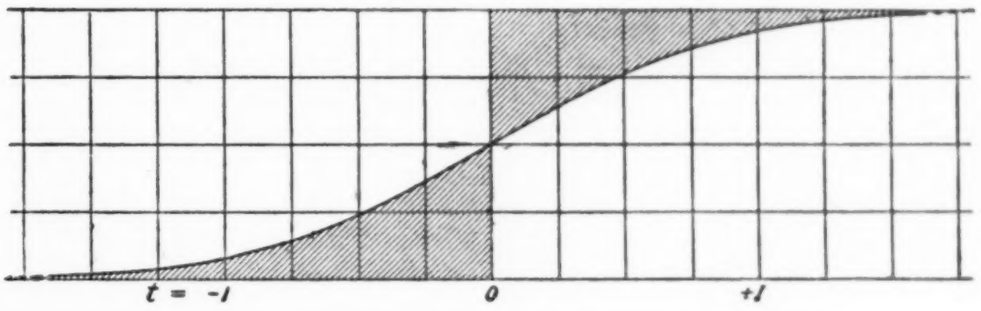

FIG. 1. The theoretical frequency curve: $y = \int_{-\infty}^{t} e^{-t^2} dt$.

to be investigated. It was therefore decided to stop with the number planned and a method of computation was worked out to suit the case.

This is based on the fundamental table of Fechner, in turn founded on the Gauss law of error, and consists in

finding the point on the stimulus-scale such that the sums of the 'wrong' judgments on either side are equal. Fig. 1 is a plot of the values of the Fechner table, the values of t as abscissæ and the frequencies, f, as ordinates, and it is to be noted that the ordinate at 0, the threshold, cuts the curve in such a way that the two shaded areas in the figure are equal. Further it may be shown by summating the frequency-values obtained from the table that these areas are each equal to 0.2821. For the theoretical frequency-curve then

$$\int_{-\infty}^{0} f dt = \int_{0}^{\infty} (1 - f) dt = 0.2821. \qquad (1)$$

If x represent any stimulus-value, the relation between t and x is such that $h(x - x_0) = t$, and therefore $h dx = dt$. The above then becomes

$$h \int_{-\infty}^{x_0} f dx = h \int_{x_0}^{\infty} (1 - f) dx = 0.2821. \qquad (2)$$

Knowing the values of $\int_{-\infty}^{x} f dx$ and $\int_{x}^{\infty} (1 - f) dx$ for all values of x would enable us from the above double equation (2) to find the value of x_0 for which these two are equal, and at the same time to find the value of h from their common value at the point x_0.

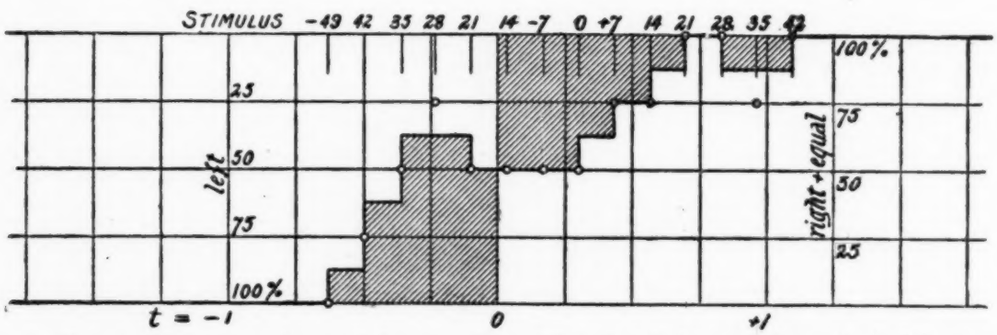

FIG. 2. The experimental frequencies. The threshold and the value of h were first computed, then the value of t corresponding to each experimental stimulus. Against these are plotted the frequencies (small circles) to illustrate the method of computation. Compare with Table I.

How these values may be worked out from a group of observations of limited number at each stimulus-point can be made clear from Fig. 2 and Table I.

TABLE I

METHOD OF COMPUTATION OF THRESHOLD AND DIFFUSION

Compare with text and Fig. 2.

Stimulus $= x$	−56	−49	−42	−35	−28	−21	−14	−7	0	7	14	21	28	35	42	49
$w = r + e$	0	0	1	2	3	2	2	2	2	3	3	4	4	3	4	4
l	4	4	3	2	1	2	2	2	2	1	1	0	0	1	0	0
For the intervals Δx: f	0	.125	.375	.625	.625	.500	.500	.500	.625	.750	.875	1.000	.875	.875	1.000	
$1-f$	1.000	.875	.625	.375	.375	.500	.500	.500	.375	.250	.125	.000	.125	.125	0	
$W = \sum_{-\infty}^{x'} f\Delta x$	0	0.125	0.500	1.125	1.750	2.250	2.750	3.250	3.875	4.625	5.500	6.500	7.375	8.250		
$L = \sum_{x}^{\infty} (1-f)\Delta x$	4.750	3.875	3.250	2.875	2.500	2.000	1.500	1.000	0.625	0.375	0.250	0.250	0.125	0		

In the present special case Δx is constant throughout and equal to 7 points on the scale. For simplicity it is taken as unity in computing the last two lines of figures, and the factor 7 is introduced later in computing the value of h. See equation (3), and footnote.

In Fig. 2 the experimental frequencies obtained at the various stimulus-points in a specimen group of experiments are indicated by the small circles. The mean frequency, f, taken as applying over any interval Δx, extending from x' to x'', is the mean of the two frequencies at x' and x''[1] and a value $f\Delta x$ is so obtained which approximates the area of the experimental frequency-curve included between the ordinates x' and x''. By progressively adding these products $f\Delta x$ from the point where $f = 0$, and similarly treating the products $(1 - f)\Delta x$, the values of W and L[2] of the table are respectively obtained. Inspection of these values shows that they are equal somewhere between $x = -21$ and $x = -14$. Linear interpolation locates the point at -15.75, which is therefore the value x_0 sought, for at this point

$$W = L = 2.125 \times 7, \qquad (3)$$

[1] If the numbers of experiments at x' and x'' are unequal, say n' and n'' respectively, and of these w' and w'' respectively are the numbers of judgments of a certain class, the weighted mean frequency for the interval x' to x'' will be:

$$\frac{\frac{w'}{n'}n' + \frac{w''}{n''}n''}{n' + n''} = \frac{w' + w''}{n' + n''}.$$

[2] If the steps of the stimulus-scale (Δx) are unequal each f and each $(1 - f)$ should be multiplied by the corresponding Δx before this addition is performed. In the present case these are all equal (7 points on the scale) and are not incorporated in the values of W and L given in the table. Under the circumstances it is only necessary to introduce this factor when h is to be computed, which is done here.

and since W and L are respectively approximations to the two integrals in (2) we have further

$$hW = hL = 0.2821, \tag{4}$$

from which

$$h = \frac{0.2821}{2.125 \times 7} = -.0190$$

and the probable error $\left(= \frac{0.477}{h} \right)$ is 25.2.

This method of computation depends on two assumptions:

(1) That the deviations of the threshold from its mean position follow the Gauss law of error. This assumption is also necessary in threshold determination by the conventional method of constant stimuli.

(2) That it is approximately true that for the theoretical frequency-curve

$$\frac{f' + f''}{2} \Delta x = \int_{x''}^{x'} f dx.$$

Consequently the stimulus-intervals must be sufficiently short so that the error introduced will be small enough to be negligible in proportion to the other possible errors inherent in the experimental conditions and in the method of computation. Further, the stimuli must be so chosen as to be representative of the entire uncertain region.

It is to be added that by this method no observation is left out of account. This can not be said of the method of limits, which completely ignores all those judgments which lie between the two critical judgments of the series. The method is even applicable to a series of one judgment on each stimulus, giving in such a case an approximate threshold value and measure of diffusion.

The fundamental assumptions and possibly also the procedure are perhaps not free from all objections. The method is an approximation and is to be judged as such. It furnishes a value for the threshold and an index of its fluctuations in the form of a probable error, with (in the writer's opinion) as great accuracy as is warranted by the data from which these results are derived.

Results

Each group of 100 judgments furnished, by the method of computation just discussed, two points in the stimulus scale: one corresponding to the appearance of greater brightness on the left half of the field, and one on the right. For each of these it was possible to work out a measure of diffusion in the form of probable error as described in the foregoing. This latter is in what follows simply designated 'diffusion' and is always expressed in the same units as the threshold discussed in connection with it. For such a group of 100 experiments the mean threshold is one half the stimulus-interval between these two points on the scale. Similarly the diffusion is the mean of the two diffusion values applying to the right and left threshold points respectively.

Table II

Observer *C*

	Brightness		Absolute		Fractional	
	Field	Surroundings	Threshold	Diffusion	Threshold	Diffusion
a	436.	17.3	1.37	2.50	0.32%	0.57%
b	128.	17.3	0.354	0.623	0.28	0.49
c	35.3	17.3	0.0969	0.211	0.27	0.60
o	17.6	17.3	0.0439	0.0859	0.25	0.49
d	8.92	17.3	0.0378	0.0643	0.42	0.72
e	2.11	17.3	0.0159	0.0299	0.75	1.42
f	0.538	17.3	0.0160	0.0259	2.97	4.81
g	0.0	17.3	0.0126	0.0212	——	——
u	17.5	121.	0.145	0.245	0.83	1.41
v	17.6	46.0	0.0695	0.130	0.40	0.74
(*o*)	(17.6)	(17.3)	(0.0439)	(0.0859)	(0.25)	(0.49)
w	17.6	8.64	0.0504	0.0957	0.29	0.54
x	17.6	2.15	0.0595	0.108	0.34	0.62
y	17.6	0.547	0.0638	0.136	0.36	0.78
z	17.6	0.0	0.0721	0.106	0.41%	0.60%

Each result given in Tables II., III. and IV. is the mean of the five obtained from the five groups of experiments with one observer under that set of experimental conditions. The results are stated in the tables as absolute brightness-difference, and in the last two columns under 'Fractional' as difference per cent. brightness of the less bright half of the field. Table V. gives the mean results for the three

observers. Except the last two columns all values in these tables are expressed in candles per square meter.

TABLE III

OBSERVER *J*

	Brightness		Absolute		Fractional	
	Field	Surroundings	Threshold	Diffusion	Threshold	Diffusion
a	436.	17.3	1.68	2.73	0.38%	0.63%
b	128.	17.3	0.351	0.659	0.27	0.52
c	35.3	17.3	0.0941	0.158	0.27	0.45
o	17.6	17.3	0.0378	0.0741	0.22	0.42
d	8.92	17.3	0.0274	0.0437	0.31	0.49
e	2.11	17.3	0.0133	0.0231	0.63	1.10
f	0.545	17.3	0.0116	0.0141	2.13	2.59
g	0.0	17.3	0.00806	0.0130	——	——
u	17.5	121.	0.104	0.140	0.59	0.80
v	17.6	46.0	0.0500	0.0870	0.28	0.50
(*o*)	(17.6)	(17.3)	(0.0378)	(0.0741)	(0.22)	(0.42)
w	17.6	8.64	0.0399	0.0702	0.23	0.40
x	17.6	2.15	0.0425	0.0985	0.24	0.56
y	17.6	0.547	0.0398	0.101	0.23	0.57
z	17.6	0.0	0.0490	0.128	0.28%	0.73%

Since the results of Tables II. to IV. are the means of five, which are each in turn the mean of two, a right and a left, there remain to be considered the variations of these among themselves. They are given in Table VI., where all

TABLE IV

OBSERVER *M*

	Brightness		Absolute		Fractional	
	Field	Surroundings	Threshold	Diffusion	Threshold	Diffusion
a	436.	17.3	2.72	2.66	0.62%	0.61%
b	128.	17.3	0.690	0.806	0.54	0.63
c	35.3	17.3	0.164	0.206	0.47	0.59
o	17.6	17.3	0.0672	0.101	0.38	0.57
d	8.92	17.3	0.0614	0.0763	0.69	0.86
e	2.11	17.3	0.0180	0.0328	0.85	1.56
f	0.538	17.3	0.0170	0.0197	3.17	3.66
g	0.0	17.3	0.0102	0.0238	——	——
u	17.5	121.	0.137	0.217	0.78	1.24
v	17.6	46.0	0.0874	0.144	0.50	0.82
(*o*)	(17.6)	(17.3)	(0.0672)	(0.101)	(0.38)	(0.57)
w	17.6	8.64	0.0994	0.131	0.57	0.75
x	17.6	2.15	0.130	0.118	0.74	0.67
y	17.6	0.547	0.124	0.143	0.70	0.82
z	17.6	0.0	0.146	0.177	0.83%	1.01%

TABLE V

THREE OBSERVERS, GEOMETRIC MEAN VALUES

	Brightness		Absolute		Fractional	
	Field	Surroundings	Threshold	Diffusion	Threshold	Diffusion
a	436.	17.3	1.84	2.63	0.42%	0.60%
b	128.	17.3	0.441	0.692	0.35	0.54
c	35.3	17.3	0.114	0.190	0.32	0.54
o	17.6	17.3	0.0482	0.0863	0.27	0.49
d	8.92	17.3	0.0399	0.0599	0.45	0.67
e	2.11	17.3	0.0156	0.0283	0.74	1.34
f	0.540	17.3	0.0144	0.0190	2.71	3.57
g	0.0	17.3	0.0101	0.0183	——	——
u	17.5	121.	0.127	0.196	0.73	1.12
v	17.6	46.0	0.0672	0.117	0.38	0.67
(*o*)	(17.6)	(17.3)	(0.0482)	(0.0863)	(0.27)	(0.49)
w	17.6	8.64	0.0585	0.0958	0.33	0.55
x	17.6	2.15	0.0691	0.108	0.39	0.61
y	17.6	0.547	0.0680	0.125	0.39	0.71
z	17.6	-0.0	0.0802	0.134	0.46%	0.76%

TABLE VI

VARIATIONS IN THE RESULTS OF SEPARATE SERIES PER CENT. MEAN VALUE

For the Various Sets of Conditions

	Threshold				Diffusion			
	Left	M.V.	Prac.	m.v.	Left	M.V.	Prac.	m.v.
a	150	27	15	15	97	13	5.8	13
b	138	28	9	20	96	13	0.3	13
c	135	31	11	27	94	20	9.3	15
o	104	25	6	26	100	13	3.2	13
d	118	26	13	19	98	23	1.7	19
e	149	28	18	22	94	9	1.5	5
f	121	34	20	17	95	19	7.0	13
g	142	47	25	34	96	22	7.3	21
u	147	36	26	18	92	15	3.3	8
v	125	28	10	26	103	15	5.0	12
(*o*)	(104)	(25)	(6)	(26)	(100)	(13)	(3.2)	(13)
w	112	31	17	23	101	17	2.2	16
x	145	24	11	16	94	17	5.0	15
y	147	23	7	17	94	18	6.0	17
z	140	22	3	17	99	22	7.3	21
For the Different Observers								
C	141	26	12	20	97	17	4.6	14
J	141	27	10	20	97	18	9.5	13
M	118	34	19	24	96	17	−0.1	16
Final Averages								
	134	29	14	21	97	17	4.6	14

the values are expressed, for purposes of comparison, per cent. of the corresponding mean values.

It is to be noted that the left threshold was almost invariably larger than the right. A larger difference had to be added to the left half of the field than to the right in order to be at the point of perceptibility. This difference is expressed in the first column of figures in Table VI. under 'Left.' The value given is the left threshold per cent. of mean right and left. The final average of these is 134, meaning that on the whole the left threshold is about twice (134 : 66) as large as the right.

The next column 'M.V.' gives the mean variation of the five threshold values. The third column 'Prac.' gives the practice effect as it applies to the threshold, that is, the average decrease (per cent. mean) found to have taken place between the succeeding groups of 100 experiments under like conditions. It was computed by the method of least squares as the value of m in the equation $y = -mx + c$, where y is the threshold for the group and x its ordinal numeral in the course of five. This equation was selected as a first approximation to the unknown practice function.

Obviously a certain fraction of the mean variation as given in the second column may be supposed to be due to the effect of practice in reducing the value of the threshold. If the thresholds conformed accurately to y in the formula $y = -mx + c$ there would be, in a group of five, a mean variation due to this fact alone equal to $1.2m$, consequently the mean deviation from the value of y could not be expected, on the whole, to be as great as the mean deviation from the flat mean. It was thought too that the mean variation from y would furnish a better index of the effect of purely accidental factors on the uniformity of the results. This was therefore computed and its values appear in the next column (m.v.) of the table. It is to be noted that its value is by no means the difference between the gross M.V. and that ($1.2m$) ascribed to the effect of practice.

In the last four columns of the table the diffusion-values have been treated in a manner exactly parallel to the treatment of the thresholds just described.

Discussion

Deviations from the Mean.—As to the variations just described, a glance at the last line of Table VI. will show that the threshold is much more variable on the whole than the diffusion. The gross mean variation of the latter is some 40 per cent. less than that of the former and the practice effect 67 per cent. less. As to the preponderance of the threshold-value for a difference added to the left half of the field, we have seen that the left threshold is about twice as great as the right. For the diffusion the difference is all but negligible, the ratio left to right being 97 : 103 and is in the contrary direction to the similar difference in the case of the threshold.

The preponderance of the left threshold is sufficiently marked to be worth some discussion in detail. It might be explained in several ways and the considerations in which the present work is capable of throwing light on the point will be taken up at once.

First, as to whether the use of one eye or the other may throw the point of no apparent difference to one side or the other. Two of the observers (*C* and *J*) used the right eye exclusively, the other one (*M*) the left. It is to be noted that in all three cases the left threshold is the greater, but that this difference per cent. in the case of *M* is less than the mean difference as 18 : 34. Since the threshold in the case of *M* is (mean of 14 cases) 1.45 times the mean threshold for the three, the absolute difference in this particular is as 26 : 34. That is, neither absolutely nor relatively is the difference between the left and the right threshold as great for *M* as it is on the average. Nevertheless the use of the left eye did not reverse the disparity as it occurred for the right eye, either in the case of the threshold or its diffusion, and for that reason the use of one eye can hardly be held to account for the one-sidedness of the judgments.

Another possibility is that the field had an initial difference or non-uniformity of brightness in the direction of higher brightness on the right half. Such a difference if of threshold magnitude might easily escape detection with the photometer

and would probably tend to the apparent diminution of the right threshold. If, however, this were the case the initial difference would be a constant fraction of the field-brightness and the difference between the right and left thresholds would tend to disappear as the threshold became larger and larger relatively to the field-brightness, as at *f* and *g*. More especially would this be so in the case of *g*, since here the initial brightness of the field is so small that it was not possible to see the image of the field projected in the field of the photometer. Inspection of the table shows that at *g* the preponderance of the left threshold is greater than the mean preponderance and stands sixth in order in the series of fourteen cases. And here an initial difference between the two halves of the field is out of the question.

The observer announced his judgment by depressing a telegraphic key, once for 'left side brighter' and twice for 'right.' It is supposable that where his sense-impression was more or less indeterminate he might be influenced by some sort of preference in his choice of the two reactions. If the difference between the left and right thresholds is to be explained by this it would seem to follow that this difference would go hand in hand with the indeterminateness of the sense-impression. The latter would be expressed by the relative magnitude of the mean variation. Against this possible explanation is the fact seen from the table, that at *o* where the field and its surroundings are of equal brightness the right and left thresholds are nearly equal, the inequality increasing in all cases with inequality of brightness between the field and its surroundings. That is, at *o* there is a minimum preponderance of the left threshold in the two series *a* to *g* and *u* to *z*. The mean variation shows no such minimum, but rather a progressive increase from *a* to *g* and from *z* to *u*.

There seems then to be nothing left but to state the fact that the left threshold is larger than the right. This "space error" is larger the greater the difference in brightness between the field and its surroundings for either direction of that difference.

The mean variations (M.V.) show a very definite trend, namely to be higher at those points where the surroundings are brighter than the test-field (at *u* and *g*) and *vice versa* (lower at *a* and *z*). This would seem to be due to a similar trend in the practice effect which also shows a tendency to decrease from *u* to *z* and from *g* to *a*. This decrease is not so regular as in the case of the mean variation in that there seems to be a minimum in its course at *o*, the point of equality of field and surroundings, but since the M.V.'s show no definite trend of this sort we may conclude that the practice effect is the cause of it. The effect of practice, then, is on the whole greater with a contrast-darkened field.

Similarly considered, the diffusion-values show, in a less definite way, certain consistent variations. As was stated, the inequality of these values for the right and left sides of the test-field was in the opposite direction from the corresponding difference in the case of the threshold, and was relatively much smaller in amount. That is, while the threshold on the left side is in general larger there is at the same time a greater consistency of judgment. And the inequality seems to increase in the direction of less diffusion on the left side, progressively with the increase of brightness-inequality in either direction between the test-field and its surroundings.

The mean variations distribute themselves differently from those of the threshold, and it is only in a slight degree that they show any consistent departure from uniformity. Further it is difficult to think of the significance of such departures in terms of concrete facts. It does not therefore seem profitable to regard them—and the same is to be said of all of the last three columns of Table VI., including the practice effect—as more than an index of the consistency of the diffusion-values of the preceding tables. Viewed as such they indicate a slightly greater consistency of the diffusion-values at *a* and *u* than at *g* and *z*, that is the diffusion-values seem to be more consistent on the whole where the brightness-conditions of the visual field are at an absolutely higher level, irrespective of the relative brightness of the test-field and its surroundings.

Individual Differences.—In general, the thresholds of the two observers *M* and *J* might be said to vary in a parallel way with changes in conditions, although this is not strictly true.

The threshold of *M* is on the whole large, that of *J* small; the wide difference probably being due to the lack of practice on *M*'s part. This is indicated by the fact that his practice effect is larger than the mean practice effect as 19 : 14 relatively to the respective means, or, since his threshold is 1.45 of the mean his practice effect is to the mean as 27 : 14 in absolute amount.

Observer *C* stands, with respect to the general magnitude of his threshold, between the two others. At the point of equality of brightness between test-field and surroundings, *o*, his threshold is not much in excess of that of *J*; but it shows a tendency to change with changes in conditions in a way that is far from parallel with the changes in the other two. These deviations are indicated in the following:

Ratio of Brightness, Test-Field / Surroundings	Due to	
	Increase	Decrease
	of Absolute Brightness	
High	Increase of Test-Field *o* to *a* Parallel increase of thresholds *M* and *J*. Less in the case of *C*, so that at *a* his is below that of *J*.	Decrease of Surroundings *o* to *z* All increase; *M* greatly, *C* moderately, *J* scarcely at all so that here *C* becomes progressively *worse* than *J*.
Low	Increase of Surroundings *o* to *u*	Decrease of Test-field *o* to *g*
	Uniformly a parallel increase in the thresholds of *M* and *J*, with that of *C* diverging from that of *J* and coming, at the extreme conditions (*u* and *g*), to coincide with that of *M*.	

The above scheme is only to be taken as showing the relatively different tendencies of the three observers as their results fluctuate with changes in the conditions. What may be drawn from it in the way of conclusion is that as the test-field becomes darker than its surroundings *C*'s threshold increases relatively more than that of the others; while in the opposite case the result depends upon the absolute brightness of the conditions—with the test-field brighter than

the surroundings his threshold becomes relatively larger than that of the others at low absolute brightness, and smaller at high absolute brightness.

It seems then that the vision of this observer is on the whole less adaptable to low brightness-conditions, more especially where the condition is one of an object of brightness which is low relatively to its surroundings.

The Effect of Different Brightness-Conditions.—The final results stated in Table V. are graphically shown in Figs. 3 to 5 inclusive.

The difference threshold may be viewed in two ways: first as an absolute quantity, a certain difference in brightness; or second, as a fraction of the absolute brightness of the field with respect to which it is the least perceptible difference. The results have here been treated in both ways.

In Fig. 3 are plotted as ordinates the absolute differences in candles per square meter. The abscissæ are according to the case: in the curves *ag*, *a'g'*, the brightness of the test-field, the surroundings being kept constant; and in the curves *uz*, *u'z'*, the brightness of the surroundings, the test-field being kept constant.

It is to be noted that when either of these factors is raised above the point of equality the threshold increases, and does so almost as a linear function of the variable brightness-condition, as would be expected in the case of change in the field-brightness, from Weber's law. However, the surroundings are far less effective in bringing about a threshold increase than is the brightness added to the test-field itself. Computing from the results at *o*, *u* and *b*, Table V., we find that for 1 unit of brightness added to the field the threshold increases on the average 0.0035 unit; while for a similar increase in brightness of the surroundings the threshold increases only 0.00085 or about 1/4 as much. Similarly, with respect to the diffusion-value, the surroundings are about 1/5 as effective as the field itself. For the conditions of the experiment, especially as to size of test-field, the relative 'extinction' values are then about as 1 to 4 for the surroundings and the field respectively.

The general conception of such a thing as 'extinction' value for any part of the visual field is however misleading and therefore objectionable. It implies that the threshold at a given point on the retina is invariably raised by increased

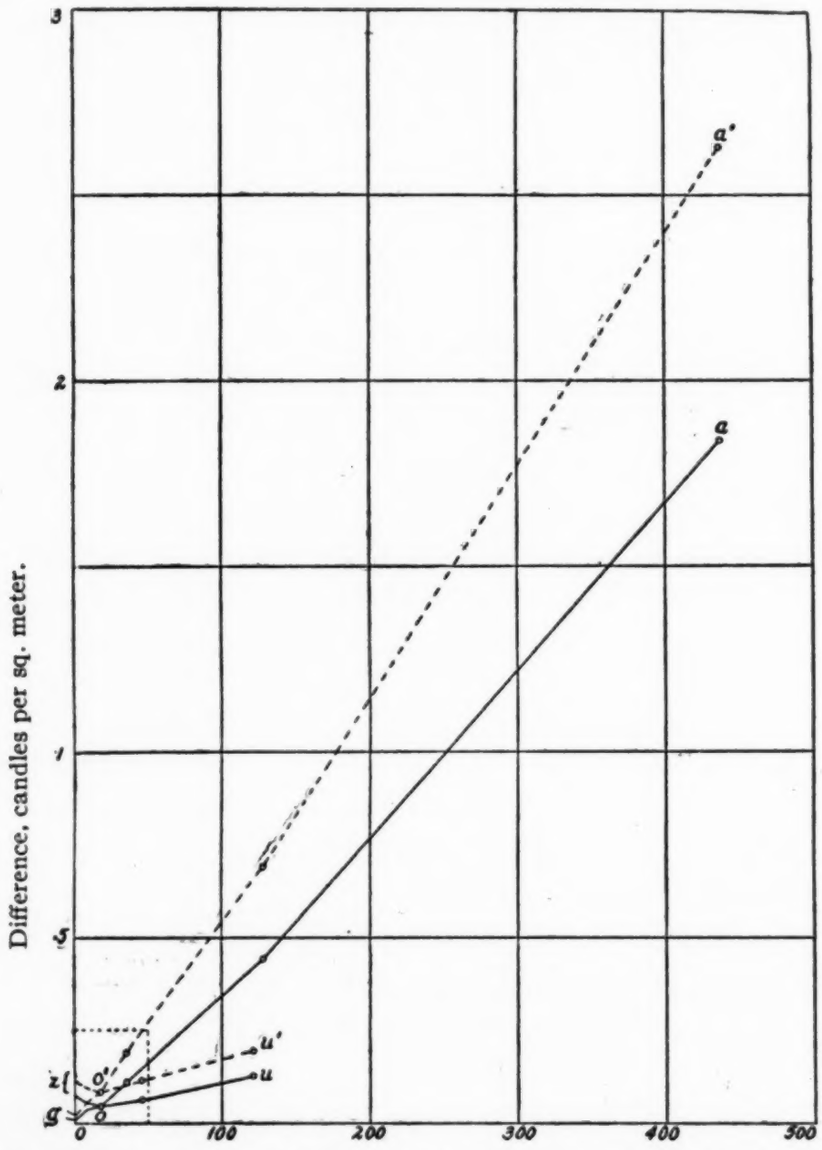

FIG. 3. Absolute values of the threshold (solid lines) and diffusion (broken lines) plotted against: *a-o-g*, absolute brightness of the test field and *u-o-z*, of the surroundings. In the former case the surroundings, and in the latter the test field were kept constant at a brightness of 17+ candles per square meter.

incidence of light upon that or any other part of the retina. Further inspection of the curve *uz* (see also Fig. 4) will show that this is not the case, for although the threshold declines

in value as the surroundings are brought down to the point of equality in brightness with the field, further reduction in the brightness of the surroundings has the opposite effect of increasing the threshold (*o* to *z*) to a final moderate value when the surroundings are made completely dark.

The other curve, *ag*, Fig. 3, shows that with the surroundings constant and the field of variable brightness a

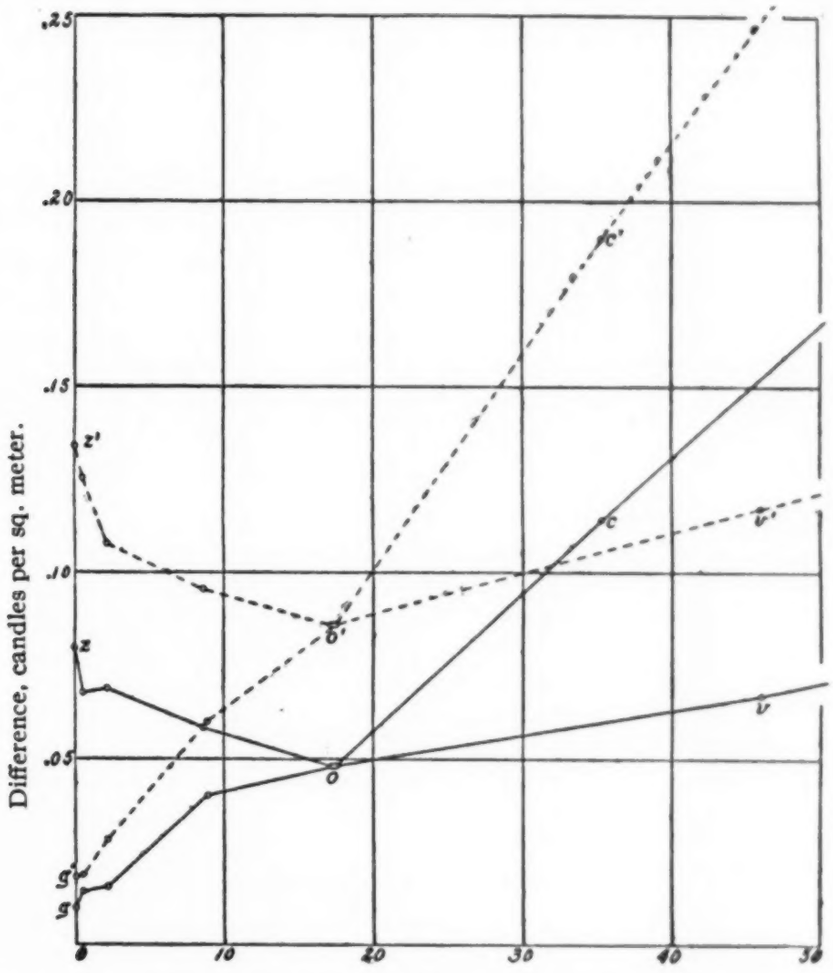

FIG. 4. Repetition of the portion of Fig. 3 enclosed in dotted lines, to a larger scale. Test field variable in curves *c-o-g*, surroundings in *v-o-z*.

change in the threshold occurs uniformly the same in direction as that in the field-brightness. But if the field alone be considered and the surroundings left out of consideration the threshold demanded by a strict interpretation of Weber's law would be represented by a straight line from the origin of coordinates. Such a line passing through the threshold at *o* would fall below the curve *ag* at all other points. Simi-

larly, the threshold according to Weber's law for a field of constant brightness, corresponding to the curve *uz* would be represented by a horizontal line, which would necessarily assume a similar relation to *uz*. The tendency is, then, for the threshold to assume a minimal value at or near the point of parity of field and surroundings.

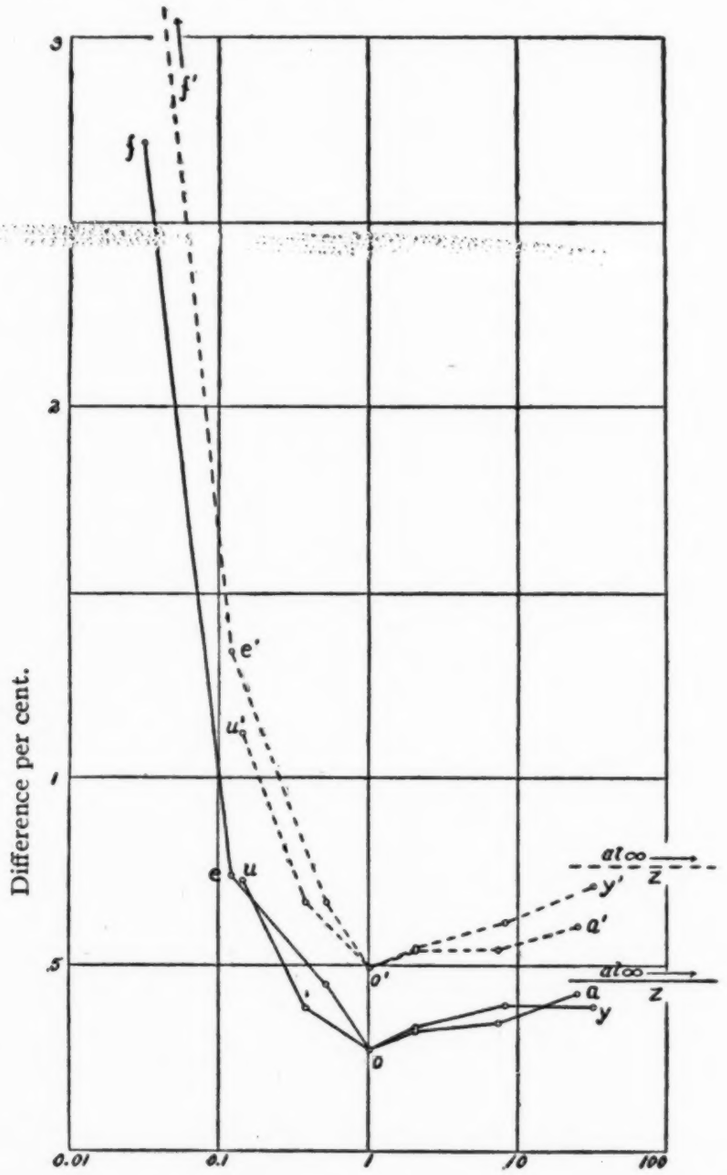

FIG. 5. Fractional threshold (solid lines) and diffusion values (broken lines) plotted against ratio of brightness of test field to that of surroundings. This last is plotted logarithmically while the numbers appearing are the actual values of the ratio.

This fact appears more clearly in Fig. 5. Here the ordinates are not plotted as brightness but as difference per

cent. brightness of test-field; and the abscissæ are not brightness units but ratios, brightness of test-field to that of surroundings. For convenience the latter ratios are plotted logarithmically.

What appears at once is (and what is said here applies to the diffusion-values as well, a' to f' and u' to y') that the values from a to f, and from u to y so plotted, give quite similar curves, and the threshold as a fraction is a fairly definite function of the ratio that obtains between the test-field brightness on the one hand and the brightness of the surroundings on the other. When this latter ratio is near unity the threshold fraction is minimal. As the surroundings come to be in excess of the test-field in brightness, whether from their own increase or from diminution of the brightness of the field, the threshold fraction increases promptly and ultimately to an enormous extent. In the opposite case, when the field is relatively brighter than the surroundings, there is also an increase in the threshold fraction, but it is relatively slow and limited in amount.

In view of the relative smallness of the experimental differences mentioned in the last sentence it is perhaps well, at this point, to examine the results and determine with what degree of probability they indicate differences in the direction stated.

The mean magnitudes of the experimental differences may be obtained from Table V. (Fractional Threshold), or more precisely from Table VII., where the mean results are stated to one more decimal place under the column head T_m. The probable error of the difference is to be obtained from the probable errors of the two quantities concerned, which are, in turn, to be obtained from the mean variations of the individual quantities going to make the mean.

In Table VII., under the heading referring to each observer the first column gives the individual's threshold as plotted in Fig. 5, per cent. field brightness. The second column gives the mean variation and the third the probable error of the individual's threshold.

If T represents the individual's threshold and R the sum of the differences between it and the N separate measurements of which it is the mean, taken without regard to sign; then M.V. as here stated is expressed by the formula: M.V. $= R/TN$, that is, the mean variation is expressed as a fraction of T, the quantity to which it applies.

The probable error is found by the formula:

$$E = 0.8453 \frac{R}{N\sqrt{N-1}}$$

and the fractional probable error given in the next column of the table is:

$$\frac{E}{T} = 0.8453 \frac{\text{M.V.}}{\sqrt{N-1}},$$

which in this case, since $N = 5$, is equal to 0.423 M.V.

T_m is the geometrical mean of the three T's from which it is derived. That is, $T_m = \sqrt[3]{T_1 \cdot T_2 \cdot T_3}$, and the formula for the probable error of such a function in terms of the three T's and their corresponding probable errors is:

$$E_m = \frac{T_m}{3}\sqrt{\left(\frac{E_1}{T_1}\right)^2 + \left(\frac{E_2}{T_2}\right)^2 + \left(\frac{E_3}{T_3}\right)^2},$$

which is not the fractional error but the probable error expressed in the same units as T_m.

The last section of the table gives the successive differences (D) between the final mean thresholds, and the probable errors of these differences computed by the formula:

$$E^D = \sqrt{E_m'^2 + E_m''^2}.$$

P and $p(= 1 - P)$ are simply the two segments of the area under the probability curves in the respective cases which are separated by the ordinate $D = 0$. The form of the probability curve is determined by the value of E_d, and the values of P and p may be obtained by the help of one of a number of tables in common use, among which is Fechner's fundamental table, and p is one-half the probabilty of an accidental difference equal to or greater than the experimental difference.

TABLE VII

ESTIMATE OF PROBABILITY AS TO EXPERIMENTAL DIFFERENCES

	Observer *C*			Observer *J*			Observer *M*			Mean		Differences			
	T	$\frac{\text{M.V.}}{T}$	$\frac{E}{T}$	T	$\frac{\text{M.V.}}{T}$	$\frac{E}{T}$	T	$\frac{\text{M.V.}}{T}$	$\frac{E}{T}$	T_m	E_m	D	E_d	P	p
o	.25	.20	.085	.22	.20	.085	.38	.36	.152	.274	.017				
												.050	.031	.86	.14
c	.27	.25	.106	.27	.19	.080	.47	.49	.208	.324	.026				
												.022	.036	.66	.34
b	.28	.24	.102	.27	.19	.080	.54	.40	.169	.346	.025				
												.067	.037	.89	.11
a	.32	.28	.119	.38	.27	.114	.62	.25	.106	.423	.027				
o	.25	.20	.085	.22	.20	.085	.38	.36	.152	.274	.017				
												.059	.032	.89	.11
w	.29	.42	.178	.23	.37	.157	.57	.15	.064	.333	.027				
												.060	.035	.88	.12
x	.34	.20	.085	.24	.31	.131	.74	.20	.085	.393	.023				
												.006	.033	*.55	.45
y	.36	.24	.102	.23	.31	.131	.70	.13	.055	.387	.023			.91	
												.070	.035		.09
z	.41	.09	.037	.28	.32	.136	.83	.26	.110	.457	.027				

It will be noted that the probabilities of these successive differences are in favor of the experimental differences, with the exception of the differences *c* to *b* and *x* to *y*. Questioning in a similar way the extreme difference between *o* and *a* we have $D = 0.149 \pm 0.032$ from which $P = 0.999$ and $p = 0.001$; and for *o* and *z*, $D = 0.183, \pm 0.032$, $P = 0.99994$ and $p = 0.00006$.

Since the differences in the other direction from *o* are all of as great or greater magnitude than the ones just discussed it is scarcely necessary to question them so closely.

Attention is to be drawn to the fact that in the foregoing computation the gross values of the mean variations have been used (M.V., Table VI.), and that no allowance has been made for the practice effect. As this latter is in all cases in the same direction such allowance might legitimately be made, since in so far as it may be demonstrably present it can not be held to throw uncertainty into the experimental differences obtained.

Such a deduction would seem, on the whole, to reduce the probable errors in the ratio 29 : 21 (M.V. and m.v., last line, Table VI.) and would, if introduced, have the effect of materially augmenting the value of P (Table VII.) and diminishing p. That is, the differences are more, rather than less, significant than the last table would indicate.

The results then could be most consistently stated, perhaps, by saying that proportionality is the factor in the brightness of the visual field that predominantly determines the sensitivity of brightness discrimination. Predominantly; because an exception is to be noted. As will be seen from Fig. 5 the portions *oa* and *ou* of the curves fall on the whole below the portions *oy* and *oe* respectively, indicating smaller threshold fractions, while at the same time they represent similar conditions as to proportionality but absolutely higher brightness. What is thus stated for the threshold applies even more consistently to the diffusion-values, as will be seen by comparing *o'a'* and *o'u'* with *o'y'* and *o'e'*.

We may then conclude that if the experiments had been conducted under conditions of several-fold higher brightness the results would have been somewhat modified on the whole in the direction of higher sensitivity.

Theoretical Considerations.—The simplest explanation—or analogy perhaps—for the phenomenon of contrast that has come to the writer's attention is a physico-chemical one.[1] If we omit for the sake of simplicity the phenomena of color, and confine ourselves to the consideration of brightness simply—or, in the terminology of Hering to the consideration of the black-white scale of sensation—we may assume in the retinal elements a light-sensitive substance *S*, which under the action of light is dissociated into two substances *W* and *B*, which always tend to return by reassociation into the form

[1] The inspiration to the discussion which follows was furnished by an article by L. T. Troland (3). I wish here to acknowledge the same and excuse myself in advance if I trespass upon or misrepresent him in any way.

of the substance S. The resulting reversible reaction will be represented by the formula:

$$S \rightleftarrows W + B.$$

Obviously, increasing the amount of W or B will tend to reverse the reaction. We will assume that B is freely diffusible from one element of the retina to another while W is not. A strong reaction in one part of the retina will then increase the amount of B in another part and tend to reverse the reaction there, reducing the amount of W.

Quantitatively, the available amount of S will be a remainder, its original amount whose concentration we will say is constant, S, having been reduced by an amount equal to the concentration of W at any instant. This remainder $S - W$ is acted upon by the light-flux, whose activity will be represented by L, proportional to, or a linear function of, the flux-density. The rate at which the reaction proceeds will then be $L(S - W)$ and the rate of the reversal will be as WB. The constant necessary here we may suppose to be implied in L and we have then for the condition of equilibrium the equation:

$$L_1(S - W_1) = W_1B, \qquad (5a)$$

which we will suppose to represent the condition in that portion of the retina receiving the image of the test-field, while an exactly similar equation holds for the surrounding retina:

$$L_2(S - W_2) = W_2B. \qquad (5b)$$

Since we have assumed that B is perfectly diffusible throughout the retina its concentration at equilibrium condition will be the same at all parts as is indicated in the above. Further, if B does not diffuse out of the retina, and k is the fraction of the latter occupied by the image of the test-field we will have:

$$B = kW_1 + (1 - k)W_2. \qquad (6)$$

It will be seen from this that with very low brightness of surroundings L_2 being small, W_2 will also be small and (5a) comes to approach the form:

$$L_1(S - W_1) = kW_1^2, \tag{7}$$

whereas when the surroundings are very bright, L_2 and W_2 being very large, (5*a*) tends to take the form:

$$L_1(S - W_1) = W_1C, \tag{8}$$

in which C is constant with reference to W_1, and is the value of B from (6) when W_2 is so large that W_1 may be neglected in comparison with it.

In discussing (5*a*) it will be convenient to drop the subscripts and we then have:

$$L = \frac{WB}{S - W}, \tag{9}$$

and assuming that a constant increment in W is the condition of a threshold difference in sensation, the condition of Weber's law is expressed by: $(\Delta L/L)\cdot(1/\Delta W)$ = a constant, and $(dL/L)\cdot(1/dW)$ may be taken as a mathematical index of the value of the fractional threshold.

1. By performing the necessary operations we find that in the scheme the fractional threshold is a minimum when $W = \frac{1}{2}S$ and $L = B$.

2. Plotting the values of W, from (9), against the values of log L as abscissæ we find that there is a certain region of stimulation in this schema within which a very close approximation to Weber's law holds. That is, the curve so obtained falls, for a portion of its course, very close to a straight line.

3. If we remember the conditions for the minimum threshold given under (1) we see that the stimulus value corresponding to it may only be increased by increasing B, which again, since $W = \frac{1}{2}S$, may, from (6), only be increased by increasing W_2, in its turn dependent on an increase in L_2 as is evident from inspection of (5*b*). That is: in the schema the increase in the stimulation corresponding to the minimum fractional threshold must go hand in hand with an increase in the brightness of the surroundings and *vice versa*.

This brings us to consideration of certain serious defects in the assumptions made and the physico-chemical picture built upon them. In the first place the value of the stimulus,

L, corresponding to a minimal threshold is strictly limited, since for minimal threshold $L = B$ and B may never be in excess of S which we have assumed to be a constant. However, we have assumed L to be a function of the actual intensity and not that intensity itself. This escape involves a further assumption that the constants of this function are variable with the general level of stimulation of the retina, say with the state of adaptation, and introduces a complication that makes it appear that the present line of discussion has been carried as far as is warranted. Still, the consequence of these assumptions, that a point of intensity could be reached at which no minimal threshold is possible, is not of itself fatal. For the reason that the result was the same for the three observers who otherwise showed very striking differences it is hardly to be concluded that the minimal threshold at the point of equality of field and surroundings was due to the unintentional selection of a critical brightness for these conditions. But there is no reason to think that this state of things should necessarily hold equally well for extremely high or extremely low general brightnesses. The writer does not know of any attempt to investigate the question under these conditions. The work of König and Brodhun (4) has shown that Weber's law breaks down under these extreme conditions, and the present work would seem to indicate that the general conclusion, as to proportionality of stimuli for like results, is subject to modification in view of the absolute intensity of the general stimulation. There is, in short, no reason to think that any conclusion drawn from experimental data obtained under mean conditions is valid for the extremes.

There are other shortcomings to be mentioned as applying to the schema just outlined. The assumption has been made that the chemical action of light upon the retina brings about a temporarily enhanced decomposition or dissociation of a sensitive substance; that the products of this action are not wasted but are wholly conserved (which is biologically improbable), and that the reformation of the sensitive substance takes place wholly by reassociation and not by

regeneration. This too is out of harmony with such physiological knowledge as we possess, for it is reasonably certain that visual purple is reformed in both ways, by the recombination of its decomposition products and by regeneration from the blood-stream.

It is perhaps clear now that this physico-chemical hypothesis has not been brought in here because the writer believes it adequate as a physiological theory of vision. The aim had rather been to give an intimation of the possibilities inherent in the principles of physical chemistry as an aid to the construction of such a theory.

It is after all doubtful if the foregoing speculations are adequate to the explanation of a certain point shown in the present results. On referring to Fig. 5 it will be seen that the depression in the curves corresponding to the minimal threshold at the point of equality of field and surroundings (at *o*) is somewhat sharper than the other parts of the curves seem to warrant. This is not sufficiently pronounced to be beyond doubt, yet it is strongly suggestive of some influence at work that makes this point a critical one in a way that is not at all to be deduced from equation (9).

It would seem rather that some other form of disturbance enters here, not at all implied in the equation, but dependent on the simple fact of the presence of contrast rather than being related to it in any quantitative way; and the possibility that the presence of contrast in any considerable degree sets up disturbances in the eye, perhaps originating by reason of a 'storm' in the nervous connections of the sensory end-organs and involving reflexly the muscles through their connections.

That disturbances of the latter might readily have the effect of increasing the threshold seems quite possible in view of the work of Holt (5), who has shown that during voluntary movements of the eye a certain refractory period exists, within which retinal impressions fail to obtain conscious recognition. He further gives it as his opinion (*loc. cit.*, p. 42) that during certain parts of the reflex movements of the eyes these periods may also be present, but not demon-

strable on account of their brevity. Assuming that contrasts in the visual field set up a disturbance in the neural connections of the extrinsic muscles it is not far to a very plausible explanation of a critical minimal threshold at the point where contrast is absent.

It does not seem possible that accommodative disturbance could be of significant effect in the present case where the retinal areas concerned are so large, unless indeed it were of such magnitude as to be easily detectable at once by the observer; and needless to say, no evidence of such disturbance was apparent.

On the other hand, the pupillary unrest, possibly consequent upon the presence of contrasting brightnesses in the visual field, would seem, if present, to have important consequences. Hering has pointed out that the dimming of a stimulus gives rise to a vivid negative after-image, and a sudden pupillary contraction has the effect of dimming the actual stimulus which is the retinal image. The negative image so brought to pass would no doubt have the effect of diminishing the effectiveness of the stimulus and so increase the size of the difference threshold. It is not so clear at once that the positive image due to a sudden dilatation of the pupil will tend to obscure a brightness difference. However the work of Dittler and Orbeli (6) makes it appear that the sensitiveness of the eye in this respect is maximum when the eye is best adapted to the brightness of the stimulus. If this is generally true *any* change in the size of the pupil would tend temporarily to increase the threshold.

As to any differences in the average pupillary diameter for different experimental conditions, it is clear that these would have only the effect of changing the general intensity of the retinal image without altering the brightness ratios, and in work recently reported by Nutting (7) it was made clear that only a small fraction of the brightness difference in any two cases is compensated by change in the pupil. This would mean that the increase of brightness of the visual field in the same ratio all around would result in a similar increase in the illumination of the retinal image

throughout, but in a somewhat smaller ratio. This fact must be taken into consideration in comparing the individuals of either pair of the curves in Fig. 5 having common ordinate at *o* and *o'*. As we recede from *o* or *o'* the ordinates of the individuals of the pair represent the results at different absolute brightness, the difference being greater the more remote from *o*. The concomitant difference in the pupillary size works only an insignificant compensation as to flux density at the retina; and since in the observation of gross areas such as the halves of the present test-field minute changes in the dioptric precision of the eye are insignificant, the difference between the two members of either of these pairs of curves must be attributed to the differences in absolute brightness in the experimental conditions and not to any secondary effect.

Summary

1. A method of computation is used which is based on the same assumptions as the classical method of constant stimuli. Like the latter it yields a value for the threshold and one for the diffusion of the results, but it is applicable to a set of very few experiments on each stimulus.

2. An almost constant tendency was observed to render judgments of greater brightness on the right side, to the effect that the left threshold appears on the average twice the magnitude of the right. Examination of the conditions fails to give satisfactory explanation of this except as a 'space error.'

3. The mean variation of the threshold results as between individual series is 29 per cent. of the threshold. A fairly constant tendency for the threshold to decrease appeared as the experiments progressed, and a due allowance for this fact makes 21 per cent. seem to be a better index of accidental variations.

4. The diffusion of results shows much greater consistency than the threshold when similarly examined. The space error is negligible, the practice effect about one third that of the threshold, and the mean variation less, being 17 and 14

per cent. as compared with 29 and 21 for the threshold. Since the magnitude of the range of diffusion changes hand in hand with the threshold when the conditions change, it would seem that the diffusion of the results is a better criterion of the sensitivity of the eye than the threshold as used in the present work.

5. The chief individual difference in the observers is the relatively small adaptability of one of these to a test field of brightness low relatively to its surroundings.

6. The changes in the sensitivity of the eye due to various brightness conditions, when estimated by the value of the fractional threshold, are seen to be predominantly dependent on the ratio that exists between the field brightness and that of the surroundings. As this ratio drops below unity the threshold increases rapidly to a large extent. As the ratio rises above unity the threshold rises, but slowly and to a small extent. Improvement with practice is more pronounced in the former case.

7. A minimum in the threshold exists at or near the point of equality of field and surroundings. This is too decided to be quantitatively due to the intensity of contrast and seems rather to be referable to the mere presence of contrast and a consequent disturbance of fixation. It is most marked in the results of the least practiced observer, *M*.

The observers, according to the initials used to designate them, are Dr. H. M. Johnson, Mr. Erich Martienssen and the writer; who wishes, in conclusion, to express his thorough appreciation of their co-operation, especially that of Mr. Martienssen, who acted as technical assistant as well.

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June, 1916.

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DISCUSSION

In the article entitled 'The Müller-Lyer Illusion with Children and Adults' in the June number of this JOURNAL there is a slight discrepancy in Tables I. and II. in column four showing the averages of the three judgments, to which Professor W. V. Bingham was good enough to call my attention. The average of the three judgments in column four is not exactly the same as the average of the three individual judgments. This, of course, would have been the case if the same number of judgments had entered into the three individual judgments. Unfortunately we omitted mention of the fact that there were a few cases at many different ages which were only given one or two judgments. We were at first concerned with arriving at norms for the three individual judgments separately, and only later were the averages for all those who had given three judgments computed. The discrepancy in the tables is slight and in no way influences the conclusions drawn from the data. I have to thank Professor Bingham for calling my attention to this oversight.

RUDOLF PINTNER

A CORRECTION

In our article entitled "A New Method of Heterochromatic Photometry," Journal of Experimental Psychology, No. 1, an error occurs. On p. 4, line 21, 3 cm. should read .3 cm.

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